University of Southern Queensland

Faculty of Engineering and Surveying

Computational Fluid Mechanics investigation of Ventilation aboard a Livestock Vessel

A dissertation submitted by

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Abstract

An investigation of the ventilation system aboard a livestock vessel was carried using a Computational Fluid Mechanics model. The heat transfer taking place within a compartment aboard the vessel was investigated in order to identify the potential for heat build up when high ambient air temperatures are experienced such as those prevalent during summer in the Middle East.

The CFD model analysed the ventilation system within a typical enclosed livestock compartment within the hull of the vessel and was able to simulate the varying temperatures within the compartment incorporating the heat generated by the livestock and varied ambient air temperatures. The effect of increasing the air velocity and varying the angle of the supply air was also studied.

The results showed that there was a significant heat build up in certain areas of the compartment. In order to ensure a habitable environment for animals when ambient the air temperature rises significantly the supply air velocity also plays an important part in maintaining lower temperatures.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results and analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I certify that the work is original has not been submitted for assessment in any other course or institution, except where specifically stated.

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Glossary of Terms

2D	Two-dimensional
3D	Three-dimensional
Aft	Towards the rear of the ship
AMSA	Australian Maritime Safety Authority
AQIS	Australian Quarantine and Inspection Service
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
Fwd	Towards the front of the ship
Inboard	Towards the centreline or inside the ship
Livestock	Farm animals such as sheep & cattle
MLA	Meat & Livestock Australia
Outboard	Towards the outside or outside the ship

1 - Introduction

In recent times the live animal export trade in Australia has come under intense media and public scrutiny due the unfortunate fate met by livestock during and after their long journey from Australian farms to overseas markets principally in the Middle East. Animal welfare groups have also been actively lobbying the Federal Government for a number of years to ban the export of live animals in order to put an end to what they claim to be suffering and ill treatment of these animals both in transit as well as at their final destination. Events such as those surrounding the MV Cormo Express where 50,000 Australian sheep were stranded on board the vessel for three weeks when their discharge was refused in Saudi Arabia have gone a long way to reinforce this perception of suffering, stress and unnecessary agonising deaths to the livestock in transit.

The flip side to this is however a very valuable and lucrative export trade that would be lost if the export of livestock were to be banned. According to LiveCorp the export trade is currently worth over $730 million annually in direct earnings to the Australian economy and is in decline from a peak of over $1 billion in 2002. The loss of this trade would have a significant impact not only on the agricultural industry but would also be felt throughout regional and rural communities of Australia who rely so heavily on primary production for their livelihood.

2 - Project Aims

The aim of this research project is to bring about a reduction in mortality rates aboard livestock vessels through improved thermal habitat and ventilation system design.

In recent times this area of the livestock export infrastructure has been the subject of a substantial amount of research and investigation with a view to producing a favourable outcome in animal welfare and the reduction of mortality rates. In Australia, LiveCorp and Meat & Livestock Australia (MLA) have together initiated the majority of research in this field.

As per the requirements of the courses ENG4111/ENG4112 Research Project, offered as part of the Bachelor of Engineering (Mechanical) program through the University of Southern Queensland further objectives of this project were to;

- Apply Computational Fluid Dynamics software to produce a 2D model of the air and heat transfer mechanisms taking place within a livestock compartment on board a livestock vessel

- Analyse the results in order to better understand the problems encountered in the removal of heat from these compartments in hot climates

- Vary the parameters that influence the heat transfer with a view to produce a favourable outcome in terms of comfort and habitat for the livestock.

- Comment on the results and provide recommendations to possible improve the current arrangement taking into the various constraints

3 - Consequential Effects

According to LiveCorp, livestock export mortality rates in 2003 were 0.11% for cattle and 0.99% for sheep amongst the 774,358 cattle and 4,748,386 sheep exported during that year. These mortality figures represent a loss of over 850 head of cattle and 47,000 sheep in a single year.

The reduction in mortality rates among livestock during sea voyages and the improvement of animal welfare are two of the key consequential effects expected as outcomes from this project. While the need for improved animal welfare is a subject with broad social appeal, it is also the ethical responsibility of the industry to ensure that the animals exported are treated with due care and without undue suffering and stress. It is expected that the findings of this research will enable the implementation of changes that will bring about significant improvement in the well being of the animals transported in livestock vessels.

The investment and cost of infrastructure for the transport of live animals is of substantial value, with the cost of converting a vessel for livestock transport costing anywhere between $30-40 million not including the vessel being converted, it is in the best interest of the livestock export industry to ensure the maximum returns from their investment.

Therefore it is expected that through a better understanding of environmental manipulation on board livestock vessels, ship owners will be able to deliver stock in far better health and with minimal losses en-route to their destination. The reduction in mortality rates will therefore have a direct impact on profitability of the live export trade.

4 - Background

Livestock export encompasses the movement of live sheep, cattle and goats from Australian farms to overseas markets.

According to LiveCorp, which is a government legislated organisation funded by the livestock export industry, in 2004 Australia exported in excess of 600,000 head of cattle, 3,000,000 head of sheep and 50,000 head of goat respectively.

The destinations for these animals were quite varied and dependent on their intended use. The principal buyers of sheep were countries in the Middle East such as Jordan, Oman, the United Arab Emirates (UAE) and Israel as well as countries in South East Asia such as Malaysia, Singapore and Brunei.

Principal buyers for breeder cattle were Indonesia, Malaysia, Philippines, Jordan, Japan, Israel and Brunei while dairy cattle were mainly exported to China, Mexico, Kuwait and the UAE. The export of dairy cattle is a new and emerging export and is seen as a having a lucrative potential for future growth within the Asian region.

4.1 - The Process of Livestock Export

The stages in the Livestock export process by sea (LiveCorp, 2004) are:

- Selection of stock for export
- Road transportation to assembly depot or feedlot close to port
- Assembly, monitoring and preparation for export at feedlot
- Road transportation to vessel from feedlot
- Loading aboard vessel
- Shipment
- Discharge

The stock is generally transported by road during the first phase of their journey using purpose built trailers towed by prime movers in b-double or road train configuration. With sheep and goats these trailers are typically loaded in a multi-tier arrangement. The animals are not usually physically restrained but their movement within the trailer is restricted through sufficient loading density and barriers. This is to prevent injury to the animals during transit. While these journeys vary in length the animals are found to suffer some degree of stress regardless, during the process.

Figure 4.1 - Road Transport of Sheep

Larger animals such as beef and dairy cattle are typically transported in single or double level trailers. The cattle are housed in individual compartments within the trailer for their road journey. This prevents the cattle from injuring one another and also minimises the possibility of damage during transit.

The livestock once at the feedlot or assembly depot are held for a period of time, which can range from a few days to a month until sufficient numbers are accumulated to meet the loading requirements of the vessel. While at the feedlot the animals are continuously monitored and health checks are carried out regularly.

From the feedlots the animals are once again transported by road and housed in holding pens at the port or loaded direct from their trailers onto purpose built livestock transport vessels for their sea journey to their destination.

Figure 4.2 - Loading of Sheep

4.2 - Livestock Vessel Design

Livestock vessels are a class of ships that are designed for and used primarily for the transport of live animals. There are three main types of livestock vessels currently in use.

4.2.1 - Enclosed Deck Vessels

Figure 4.3 - Enclosed Deck Vessels

(From www.meyerwerft.de)

These vessels are typically car carriers or car ferries that have been converted for the purpose of carrying livestock. They have large enclosed clear decks within the superstructure of the vessel and therefore they are considered a good platform for the installation of stock pens within these decks. Forced mechanical ventilation systems are also typically in place however upgrading of the extraction and supply may be necessary due to the respiration and heat generated by the livestock housed within their pens. An advantage of this type of vessel is the isolation of the animals from the elements. This allows for stricter control of their environment and habitat to a greater extent than in vessels of the open type design however they are totally dependant on the mechanical ventilation systems for their survival.

According to Meyer Werft, a German shipyard that converts vessels for livestock transport, the latest vessels typically feature automatic feed, watering and waste disposal systems.

4.2.2 - Open Deck Vessels

Figure 4.4 - Open Deck Vessels

(From www.meyerwerft.de)

Open deck vessels were more commonly built in the 1970’s and 1980’s and are typically tankers, bulk carriers or container vessels converted for livestock transport by the construction of a stock house on their foredeck. The stock house is usually open to the elements at their sides and therefore control of the environment has a different approach than that of enclosed type vessels.

The open design allows for the passage of fresh air through the stock house and therefore the ventilation system may be of a lesser capacity than that of enclosed type vessels and only supplied to pens at the centre of the stock house. These vessels too feature automated feed, watering and waste disposal systems on those built more recently however the older vessels of this type still in operation are not as well equipped.

4.2.3 - Combined Deck Vessels

Figure 4.5 - Combined Deck Vessels

(From www.sibaships.com)

Purpose built livestock vessels that are of more recent constructions tend to have both open as well as enclosed decks for animal transport. The open decks are usually situated above the main freeboard deck and utilise the advantages of natural ventilation where possible. This reduces the number of ventilation fans required compared to fully enclosed vessels.

In order to maximise the usage of available space, the hull spaces are also utilised for livestock transport and these will be typically enclosed spaces relying upon mechanical forced supply as well as exhaust fans for their air changeover.

4.2.4 - Pen Design

The configurations of stock pens on board both types of vessels vary depending on the type of stock being carried. The enclosures are typically built with galvanised steel or aluminium tubing grids and feature specially coated deck surfaces as well as interlinked passageways for the efficient loading and unloading of stock. The pen arrangements are easily configured from enclosures with a small area to larger ones by connecting adjacent pens to each other.

Figure 4.6 - Pen Design

The number of animals that can be loaded within each pen is regulated by the Australian Maritime Safety Authority (AMSA) as well as the Australian Quarantine Inspection Service (AQIS) who also play an integral part in the regulation of the livestock export industry. This loading density is based on the liveweight of the animals and also the ventilation capacity of the vessel.

4.3 - Ventilation System Design

Ventilation design aboard livestock carriers is of key importance as it has a direct impact on the health and wellbeing of the stock while in transit particularly where the vessels are sailing to hot climates such as the Middle East.

Typically ventilation systems comprise of a network of ducts carrying fresh air into the stock house, force fed through the use of large mechanical ventilation fans. These fans are usually electrically driven and supplied via the ships auxiliary engines or generators.

The Australian Maritime Safety Authority regulates the suitability and seaworthiness of vessels carrying livestock from Australian ports. AMSA Marine Orders Part 43 'Cargo & Cargo Handling – Livestock' covers a comprehensive range of criteria that need to be complied with in order to obtain a licence to export livestock aboard ships. In particular Appendix 4 of Part 43 'Livestock Services' provides details of the required ventilation arrangements as well as the mandatory number of air changes per minute required by the ventilation system within the stock house in order to ensure the welfare of the livestock. These are however the minimum requirements and may not always provide the ideal conditions in the event of extremities in weather or special requirements for animals that may be suffering stress. AMSA Marine Orders Part 43, Appendix 4 ‘Livestock Services’ is provided in Appendix B of this document for reference.

According to Dr. Tony Brightling (RSPCA, 1999) bulk supply of fresh air through mechanical ventilation fans in to animal areas is not sufficient to provide a healthy animal habitat. The ventilation system should be designed such that it provides for heat and moisture exchange in hot and humid climates, removal of ammonia and differential ventilation for different areas of the animal house to cater for higher risk stock. These factors along with watering systems to spray stock suffering from heat stress and the effective disposal of dung to reduce heat and moisture build up are requirements for providing a suitable shipboard environment for long sea voyages.

4.4 - Transport Stress

Transport stress is a physiological change in the condition of an animal caused by the need to adapt to rapid changes in its environment. According to a MLA and James Cook University joint study on transport, stress manifests itself as

- Loss of bodyweight
- Dehydration
- Reduced feed intake
- Physical injuries

- Respiratory disease

The causes and stressors in the transport of animals are identified as:

- Behavioural stress caused by restraint, overcrowding and mixing results in fear and aggression.
- Nutritional stress caused by fasting resulting in hunger and dehydration. Physical stress caused by mixing, overcrowding and weather extremes resulting in bruising injury and hypothermia
- Infectious stress caused by dust and exposure resulting in respiratory disease

5 - Literature Review

LiveCorp is a government legislated organisation that is funded by the livestock exporters and producers, and along with Meat & Livestock Australia shares the responsibility of managing and promoting the live animal export trade in Australia. These two organisations have also pioneered a significant amount of research into various facets of improving the livestock export trade and this research has also encompassed the effects on animal welfare and ways to improve it.

5.1 - Case Study No.1

In 2000, a study designated Project Number SBMR.002 was initiated into the efficacy of ventilation aboard livestock vessels. The study included a research veterinarian accompanying six voyages between Australia and the Middle East for the purpose of observation and recording data. The work was undertaken by MAMIC Pty Ltd and was jointly funded by LiveCorp and Meat & Livestock Australia. The findings of the study were published by Meat & Livestock Australia in July 2001 in a final report entitled ‘Investigation of the Ventilation Efficacy on Livestock Vessels’. The findings of the project suggest that there are a number of key airborne pollutants which can adversely affect the health of the livestock while they are onboard the vessels.

Heat has been the main factor that influences the design and effectiveness of the ventilation systems and the principal source of heat in enclosed spaces is livestock derived. By measuring the overall heat balance between the exhaust air and intake air a metabolic heat rate was derived for each type of stock of carried on the six voyages. Of particular relevance to this project is the heat generated by sheep which was found to be 3.2 W/kg in live weight.

The second biggest heat source was found to be generated by the intake air fans as the heat generated by the fan motor was carried into the compartment with the supply air and was found to add between 5 to 15% of the heat generated by the livestock.

Radiated heat from adjacent walls and ceilings was also found to be a contributory factor to heat build up within the livestock compartments. Engine Room and Fuel Tank bulkheads along with exposed decks exposed to weathering directly above the compartment were the most common sources of radiated heat.

Interestingly water vapour was also considered as a pollutant even though it is not considered such in an environmental sense. The reason for this is that an increase in moisture dissolved in the air reduces the evaporative heat loss. Animal respiration and sweating significantly added to the already high relative humidity levels experienced during the sea voyages in the Middle East and were in the order of 65 to 85%.

Carbon Dioxide, Ammonia, Methane and noise were also considered for their effect on animal comfort. Carbon Dioxide generation is directly related to metabolic activity and the level of Carbon Dioxide in the exhaust air stream was found to be a good pollutant indicator as it provided a direct measure of the ratio of upstream live weight to airflow rate. Ammonia rates were found to be generally higher than that recommended for animal housing and its possibility of being a contributory stressor to heat stress was noted. Methane levels were found to be well below explosibility limits and thus not considered any further. Noise within the compartments was mostly caused by the ventilation system itself however no adverse effects on the livestock were noted.

Stocking density is governed by the Australian Maritime Safety Authority (AMSA) Regulations (Marine Orders 43) and dictates the allowable loading density and was found to provide a constant live weight per area of approximately 275 kg/m^2 and is important not only for freedom of movement but also for ventilation efficiency. As heat is the principal pollutant to be removed by the flow of air, a reduction in the stocking density will produce similar results to increasing the ventilation rate. This is due to the fact that heat generation is directly proportional to the live weight of animals within the compartment.

The current AMSA Marine Orders 43 also has regulations for ratio of the supply air flow rate to the compartment volume space expressed as air changes per hour. According to the regulations a larger compartment volume would thus require a higher air change per hour. However, high ceiling heights lead to larger compartment volumes for a given deck area and this contradicts with loading density which is related deck area and not compartment volume. It was therefore suggested that the term 'Pen Air Turnover' (PAT) which is the ratio of air flow rate per deck area with the unit of metre per second (m/s) or air volume per hour divided by pen area, would be a more appropriate measure of ventilation requirement.

Residual time and recirculation were also found to be important factors in the measure of ventilation efficiency. When air from one compartment exhausts into another compartment which has its own supply air the time taken for the original air to reach the atmosphere is called residual time. Recirculation refers to the effect of exhaust air exiting a compartment being captured and ingested by the intake air which is being supplied to a compartment. This has the effect of reducing ventilation efficiency and if a compartment has 50% recirculated air its ventilation capacity is reduced by half and pollutant concentration effectively doubled.

The effect of airspeed on the comfort of the animals was seen to have particular importance. The study observed that animals provided with localised jetting of air showed significantly less respiration rates than those with significantly less or no air movement within a compartment. Increasing air speed was shown to decrease the skin temperature required to reject metabolic heat. The effect of air speed on the comfort also has particular relevance to this project as the CFD model was used to analyse the effect of higher air speed on the temperature distribution.

The effects of breed, size and acclimatisation were also considered in the report but since they are not directly related to this project they are not mentioned any further.

A number of attempts to define a comfort index for livestock were discussed however it was found that Wet Bulb Temperature was a particular good index of measure and suited to shipboard use as it is easy to measure with inexpensive readily available equipment.

The principal findings of the study relevant to this project and in relation to the above factors were as follows;

- Wet bulb temperature was found to be a good measure of comfort index for animals aboard livestock vessels.
- Air movement is of high importance and the air speed could be used to calculate an 'adjusted' wet bulb temperature.
- Pen Air Turnover (PAT) is a preferable unit of measure for ventilation requirement than the current air changes per hour enforced by AMSA MO43.
- Recirculation of exhaust air is a serious cause for lower ventilation system performance and should be measured to downgrade the surveyed air turnover.
- Sheep generate a metabolic heat at a rate of 3.2 W/kg live weight.

- Carbon Dioxide is a good tracer for assessing the effectiveness of the ventilation system.
- A risk range was put forward for a given wet bulb temperature and sheep were found to be generally safe from heat stress below 26°C, caution should be exercised when temperatures are between 26 - 29°C and the sheep are likely to be in danger when temperatures are in excess of 29°C.

5.2 - Case Study No.2

Project LIVE.116 was initiated by LiveCorp and Meat & Livestock Australia as a follow on from Project SBMR.002. The project was carried out by Maunsell Australia Pty Ltd and a report titled ‘Development of a Heat Stress Risk Management Model’ was published in December 2003.

The objective of the project was to develop a heat stress risk management model through data analysis, mathematical modelling and software development. The resulting ‘HS’ software provides an automated method to estimate the risk of mortality aboard livestock vessels due to heat stress on voyages from Australia to the Middle East and is currently in use by livestock exporters. The model takes into account the weather at the destination and en route, animal acclimatisation, coat and condition as well as the ventilation characteristics of the ships to predict the expected mortality rate and therefore loading densities and to some extent voyage planning can be implemented to minimise the risks.

The model for enclosed deck risk estimation was stated to depend on the type, breed, coat, condition, acclimatisation and weight of the livestock. It was also related to PAT of the vessel, the time of year of the voyage, the voyage route, destination port, duration of transit and stay in critical zones identified in the weather data.

A thorough investigation of available climatic data for the key Middle Eastern ports of disembarkation was carried out and presented. This area includes the Persian Gulf, the Gulf of Oman, the Red Sea, the Gulf of Aden, the Arabian Sea and the Indian Ocean. It was noted that available data varied in quality and accuracy and that data measurement in some cases was from location inland of the coast thus may not present accurate values for conditions at sea.

However the report did in fact provide a valuable source of tabulated wet bulb climatic data for all principal ports of discharge in the Middle East for an entire year. The data shows that July, August and September are consistently the hottest months across the Middle East region and the 98^{th} percentile wet bulb temperatures are close to or in excess of 30°C in most instances.

The report also discussed the methodology used in the CFD modelling process and while the study made use of a 3D model as a basis for building a risk analysis software model it did provide a number of animal parameters that served as a guideline to this project. The schematic of sheep representation and the total metabolic heat rate in particular were obtained from this source.

6 - Data Collection

In order to study the performance of a ventilation system on board a livestock vessel and also acquire a thorough understanding of the process and conditions faced during the livestock export process it was necessary to gather live data. The success and accuracy of this investigation was therefore reliant on access to a livestock vessel for study and for this purpose a visit was organised on board MV Becrux on the 29 and 30 of August 2005 while the vessel loading in the port of Fremantle, Western Australia.

6.1 - Vessel Details

MV Becrux is one of the most recently built livestock carriers plying the route between Australia and the Middle East and has only been in service for three years. On this particular voyage she was carrying sheep from Fremantle, Western Australia to a number of ports in the Middle East.

MV Becrux is a mono hull motor ship of welded steel construction which comprises both fully enclosed as well as open type livestock decks. Unlike most livestock vessels currently in service, MV Becrux was purpose built for livestock transport and is considered to be the most advanced within the industry.

The principal particulars of the vessel are as follows:

Length Overall	176.70 m
Breadth	31.10 m
Depth (to Deck No.6)	14.53 m
Depth (to Deck No.10)	24.08 m
Design Draught	7.70 m
Deadweight at Design Draught	10 800 tonnes
Service Speed	19.80 knots

Figure 6.1 - MV Becrux in the port of Fremantle

Decks 1 through 5 within the hull of the vessel are fully enclosed while decks 6 through 9 are of the open type. The Upper Deck (Deck 10) is the fan deck and all ventilation supply and exhaust fans are located on this deck which is 24.080 m above keel and 16.380 m above waterline.

The vessel features automated feed, watering systems and deck wash systems to ensure the survivability of the livestock on board.

6.2 - Ventilation System

The ventilation system on board consists of mechanical supply and exhaust fans located on the uppermost deck of the vessel and 84 ventilation columns extending from the Upper deck into the livestock areas. 34 columns (32 Supply + 2 Exhaust) stop above Deck No.6 and are for exposed deck ventilation only. The remaining 50 ventilation columns (26 Supply + 24 Exhaust) provide mechanical ventilation exclusively for the enclosed spaces. The exhausting of air from the enclosed and exposed decks is also improved by openings in the corridors with plastic open grid protections to allow the through movement of air.

All mechanical ventilation system electric motors are of single speed, non reversible type for open decks, while for the enclosed decks they are of reversible type. This provides for flexibility within the system as the most suitable combination for ventilation of enclosed spaces can be configured by switching the fans for either supply or exhaust air.

Figure 6.2 - Ventilation Fans located on Upper Deck

The air changeover volume from each compartment is well in excess of that required by the Australian Maritime Safety Authority regulations for any given loading density with the system typically capable of 60 air changes per hour from the enclosed spaces.

Figure 6.3 - Typical Supply Air Column in an Enclosed Compartment

Figure 6.4 - Typical Exhaust Air Column in an Enclosed Compartment

One feature of the supply air column that should be noted at this point is the arrangement of the supply air inlet opening and the method employed for directing air through the opening. As seen in Figure 6.5 the openings feature a baffle plate at a 45° angle to the flow in the column which is used to direct the flow of air through the opening. The angle of the baffle plate has and effect on the angle of the velocity resultant of the air entering the compartment. This angle has been referred to as the 'supply air stream angle' in later sections of this document.

Figure 6.5 - Baffle Plate in Supply Air Column

6.3 - Compartment Arrangement

It was most appropriate to investigate the heat transfer taking place in one of the fully enclosed compartments which are located in the hull of the vessel as these compartments are totally reliant on the mechanical ventilation system for their air supply. Deck No.4 (Aft) was chosen as a suitable compartment for study as it had enclosed decks above and below and also proved to be a convenient choice with the loading schedule at the time of the visit.

Figure 6.6 - Deck 4 (Fwd) Compartment prior to loading

Each enclosed deck within the hull is divided into two compartments, one aft and one fwd, and each of these compartments spans the breadth of the vessel. The floor space within each compartment is further divided into a series of pens and corridors. The arrangement of these pens can be easily changed as the barriers separating the pens are removable. Thus it is possible to contain animals within a single pen or provide a larger single space by opening the barriers through adjacent pens.

Each compartment has a single central loading ramp for the movement of stock in and out of the compartment.

Figure 6.7 - Deck 4 (Fwd) Compartment after loading

6.4 - Readings

A series of readings were taken over a period of hours while the vessel was loading in port.

The data gathered included;

- Size of ventilation supply and exhaust openings
- Supply and Exhaust air velocity entering the compartment
- Supply and Exhaust air temperature

- Relative Humidity
- Ambient air temperature
- Number of animals per pen
- Body temperature of animals in pens
- Temperature of surrounding walls and decks

Two sets of readings were taken in the early afternoon before the vessel was loaded. This was to acquire a point of reference for the readings to be taken when the compartment was loaded. It also provided the opportunity to decide on which compartment and pens would be the most suitable for study which was also dependant on the loading schedule.

As second set of readings was taken at approximately 8:00pm at night immediately after Deck 4 (Fwd) was loaded. Two further readings were taken at 6am the following morning after the animals had been on board overnight. This was to allow the heat load within the compartment and ensure the accuracy of the readings.

Please refer Appendix C for the table of readings taken.

6.5 - Measurement Techniques

Two instruments were used to gather the readings required for the CFD analysis.

A TSI 8386 Velocicalc hot wire anemometer was used to take readings of air velocity, dry bulb air temperature, wet bulb temperature and relative humidity. The air velocity was measured at a number of supply and exhaust column openings within each compartment and also at a number of points across each opening. For the final analysis when the appropriate pen for study was chosen, this allowed comparison with values measured at other locations. The values used are average air velocities for the supply and exhaust columns under investigation.

A Raytek MX4+ infrared thermometer was also used to measure the surface temperatures of the animals, the ship walls, decks, ceilings and ventilation column surfaces in order to check for the possibility sources of heat in addition to the livestock within the compartment.

The specification sheets for the instruments used are provided in Appendix D.

7 - Methodology

The following chapter details the process involved in building and analysing the FLUENT model.

7.1 - CFD Modelling Rationale

Computational Fluid Dynamics or CFD is the science of using a numerical process to predict the flow of a fluid, mass transfer, heat transfer or chemical reactions by solving mathematical equations that govern the physical laws such as the conservation of mass and momentum and energy equations.

The use of CFD analysis to solve problems related to fluid flow and heat transfer has a number of distinct advantages. With the use of a numerical model many scenarios can be investigated through simulation rather than physical means. This has obvious cost and safety advantages not only for dangerous and complex processes but also for any problem involving fluid flow and heat transfer. The use of CFD has been widely adopted in industry today and has been shown to greatly reduce cost and time in the design process with excellent correlation of results.

FLUENT is one of many CFD analysis tools that are commercially available at present and was selected for use in this investigation due to its availability through the Faculty of Engineering and Surveying. FLUENT provides modelling capabilities for incompressible, compressible, laminar and turbulent fluid flow problems and also various modes of heat transfer including natural, forced and mixed convection can also be modelled. FLUENT solves conservation equations for mass and momentum for all flow flows and the following forms of the equations are quoted in the FLUENT User Guide.

The general form of the conservation of mass equation valid for incompressible as well as compressible solved by FLUENT in the following form;

$$\frac{\partial \rho}{\partial t} + \nabla.(\rho \vec{v}) = S_m \qquad \textbf{(7.1)}$$

Where S_m is the mass added to the continuous phase from the dispersed second phase and any user defined sources.

Similarly the conservation of momentum equation is quoted as;

$$\frac{\partial}{\partial t}(\rho \vec{v}) + \nabla.(\rho \vec{v}\vec{v}) = -\nabla p + \nabla.(\bar{\bar{\tau}}) + \rho \vec{g} + \vec{F} \qquad \textbf{(7.2)}$$

Where p is the static pressure, $\bar{\bar{\tau}}$ is the stressor tensor, $\rho\vec{g}$ the gravitational body force and $\vec{F}$ are the external body force.

The stress tensor $\bar{\bar{\tau}}$ is given by

$$\bar{\bar{\tau}} = \mu\left[(\nabla\vec{v} + \nabla\vec{v}^{T}) - \frac{2}{3}\nabla.\vec{v}I\right] \qquad \textbf{(7.3)}$$

Where μ is the molecular viscosity, I is the unit tensor and the second term on the right hand side is the effect of volume dilation.

The transfer of thermal energy from one matter in space to another is termed heat transfer and this process takes place through conduction, convection or radiation. In order to analyse the heat transfer FLUENT solves a variation of the energy conservation equation in the following form;

$$\frac{\partial}{\partial t}(\rho E) + \nabla.(\vec{v}(\rho E + p)) = \nabla.\left(k_{eff}\nabla T - \sum_{i} h_i\vec{J}_i + (\bar{\bar{\tau}}_{eff}.\vec{v})\right) + S_h \qquad \textbf{(7.4)}$$

Where k_{eff} is the effective conductivity and $\vec{J}_j$ is the diffusion flux of species j. The first three terms on the right hand side of the equation represent energy transfer due to conduction, species diffusion and viscous dissipation respectively. S_h includes the heat of chemical reaction, and any other user defined volumetric heat source.

The CFD analysis process is typically made up of three fundamental steps to solve most problems. These steps are;

- Problem identification and pre-processing, where goals for the analysis are laid out, the domain to be modelled is identified and the mesh is created.
- Solver execution stage where the numerical model and boundary conditions are defined and the solution is computed
- Post-processing where the results are analysed and changes to the model are considered and implemented is required.

The pre processing stage of the FLUENT analysis requires the use of a geometry modeller and the GAMBIT was used for this purpose. Gambit uses a Graphic User Interface (GUI) to help with this process.

7.2 - The Compartment Model

In order to understand the effects and mechanisms of the heat build up within a livestock compartment due to climatic change when vessel approaches the Middle Eastern region which results in increased ambient air temperatures, a single compartment was chosen for analysis. The compartment was typical of those located within the hull of the vessel on a fully enclosed deck and was to provide a representative indication of the conditions that can be expected within other compartments on the vessel for similar environmental conditions.

Due to constraints in time and resources the FLUENT analysis was to be of a 2D model of a single livestock compartment within the hull of the vessel. This 2D model was to depict the heat transfer taking place within a one metre unit depth of the compartment.

The first step after identifying a suitable compartment within the vessel during the data gathering stage was to define the physical parameters of the domain. A CAD drawing of the compartment cross section was prepared in order to define the problem to be analysed and can be referred in Appendix E

Only one side of the vessel was to be modelled as each compartment was symmetrical across the vessel centreline. The cross section has a single supply air column bringing fresh air into the domain and a single exhaust air column to remove air from the domain. Simple geometric shapes have been used to depict the physical area occupied by the livestock and these shapes have been replicated within the compartment to distribute the effects of heat generation similar to that of the actual situation.

GAMBIT is a software package used for building and meshing models for computational fluid dynamics analysis using FLUENT as well as a number of other software packages. The GAMBIT software simplifies the basic steps of building, meshing, and assigning zone types to a model.

In order to build the GAMBIT mesh of the compartment the CAD cross section was further simplified and geometrical shapes were chosen to represent the supply air inlet, the exhaust outlet and the animals within the compartment. The supply air column has two inlets into the domain which separated by the diameter of the column. The exhaust column has only one outlet which is at the front face of the exhaust column. The animals were modelled to only account for their greater heat generating surfaces and thus their limbs were ignored in the model. The distribution of the animals accounts for the specific loading density of the compartment being analysed but positioning within the compartment is representative only.

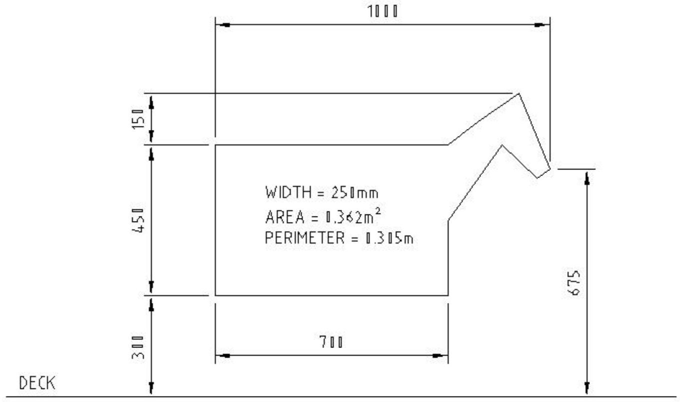

Figure 7.1 - Schematic of Sheep Representation

Quadrilateral elements with a Pave type grid were used to mesh the model.

The complete GAMBIT generated mesh of the compartment can be viewed in Appendix F.

7.3 - Assumptions

As mentioned previously the model is a 2D analysis and thus a number of assumptions have been made to simplify the model and analysis. The first and foremost assumption in a 2D model is that all fluid flow is the *x-y* the plane and there is no z component t the flow. A steady incompressible flow has also been assumed with no change in properties with respect to time.

The effects and influence of radiation heat transfer have been neglected in this analysis due to the predominance of forced convection caused by the high air velocities within the compartment. Also during data gathering there was a lack of evidence to suggest the presence of bodies that would emit a high degree of radiated heat such as engine room bulkheads or exposed decks within the proximity of the compartment under investigation.

I t is also important to note that in this analysis that effects of airborne water vapour or humidity have not been considered due to time and resource constraints. Therefore all heat transfer does not include any evaporative cooling effects which are dependant on the relative humidity of the air. As such all air temperatures quoted in this investigation are dry bulb temperatures unless otherwise stated.

7.4 - Analysis

Once the compartment mesh was generated and the initial condition defined as measured during the visit on board the vessel there were a series of 6 cases analysed in total. The basis for deciding on the cases for analysis was the varying of parameters to investigate the effects of rising ambient air temperature and also looking at possible changes to the existing ventilation arrangement to improve the conditions within the compartment. A summary of the cases analysed in FLUENT are listed in Table 7.1.

Case	Description	Ambient Air Temperature (°C)	Air Velocity (m/s)	Supply Air Stream angle
0	Measured condition	13.5	10.5	45°
1	Increased Air Temp	32.0	10.5	45°
2	Varied angle of Supply	32.0	10.5	60°
3	Varied angle of Supply	32.0	10.5	30°
4	Increased velocity	32.0	12.5	30°
5	Increased velocity	32.0	12.5	45°

Table 7.1 - Cases Analysed in FLUENT

7.4.1 - Case 0

This condition represents the initial ‘as measured’ condition of the compartment. Through later stages of the analysis while varying the parameters to investigate the possibility of reducing the heat build up within the compartment it became apparent that the stream angle of the supply air had a significant effect on the temperature distribution. The 45° stream angle refers to the existing arrangement on the vessel as mentioned in Section 6.2.

7.4.2 - Case 1

This case investigates the effect of an increase in ambient air temperature. As reported by MLA LIVE.116 (2003, page 15) the mean wet bulb temperatures in the north of the Persian Gulf the during the months June to September approach 26°C and maximum values regularly exceed 33°C. Therefore it was considered a reasonable assumption to use a dry bulb temperature of 32°C as a benchmark to study the variations of heat within the compartment at this elevated temperature.

7.4.3 - Case 2

This case investigates the effect of varying the supply air stream angle to 60° down from the horizontal. This would result in the air being directed towards the deck and the backs of the animals in the immediate proximity of the supply air column.

7.4.4 - Case 3

This case investigates the effect of varying the supply air stream angle to 30° down from the horizontal. This would result in higher velocities further away from the supply air column opening.

7.4.5 - Case 4

This case investigates the effect of increasing the supply air velocity by 2m/s with a supply air stream angle of 30° down from the horizontal. This is to analyse the effect of directing higher velocities further away from the supply air column.

7.4.6 - Case 5

This case investigates the effect of increasing the supply air velocity and retaining the current arrangement with a supply air stream angle of 45°.

7.5 - Boundary Conditions

Boundary Condition definition in CFD analysis is of significant importance in order to generate a simulation that closely replicates the physical model. The boundary conditions define the variables that govern the flow of fluid and heat. The boundary conditions used to define the variables in the FLUENT compartment model were velocity inlet, pressure outlet, symmetry and wall. The following tables provide a summary of boundary conditions used in the model.

Boundary Name	Type	Velocity Method	Velocity Magnitude (m/s)	Turbulence Method	Turbulence Intensity (%)
supply-air-inbd	Velocity Inlet	Magnitude & Direction	10.5 / 12.5	Intensity & D_H	10
supply-air-outbd	Velocity Inlet	Magnitude & Direction	10.5 / 12.5	Intensity & D_H	10

Table 7.2 - Velocity Inlet Boundary Conditions

Using magnitude and direction for the velocity inlet boundary condition allowed the angle of the supply air to be varied as discussed in the case definitions. Two values were used for magnitude as mentioned.

Boundary Name	Type	Gauge Pressure (Pa)	Backflow Temp. (°C)	Turbulence Method	Turbulence Intensity (%)
exhaust	Pressure Outlet	0	13.5 / 32	Intensity & D_H	10

Table 7.3 - Pressure Outlet Boundary Conditions

The exhaust was defined as a pressure outlet and the gauge pressure at the position of the exhaust outlet within the model was defined as per the above table.

Boundary Name	Type	Thermal Condition	Heat Flux (W/m²)	$\bar{h}_c$ (W/m².K)	Free Stream Temperature (°C)
ceiling	Wall	Heat Flux	0	-	-
deck	Wall	Heat Flux	0	-	-
internal-walls	Wall	Heat Flux	0	-	-
livestock	Wall	Heat Flux	168	-	-
ship-side	Wall	Convection	-	23.6/23.1	13.5 / 32

Table 7.4 - Wall type Boundary Conditions

The livestock shapes were defined as a wall type boundary that produced a set heat flux within the domain. The calculation for this as well as the convection heat transfer from the ship side is detailed in the following section.

7.6 - Calculations

The following calculations were used to determine boundary condition values for use in the FLUENT analysis.

7.6.1 - Heat Flux generated by livestock

Number of Sheep per Pen	=	60
Floor Area of Pen	=	$17.6m^2$
Sheep Stocking Density	=	$\frac{60}{17.6}$
	=	3.4 animals per m^2
Sheep per metre depth in model	=	$\frac{3.4}{1}$
	=	3.4 animals per m
Width of stock pen in model	=	4.5m
Sheep per stock pen in model	=	4.5 x 3.4
	≈	16 animals

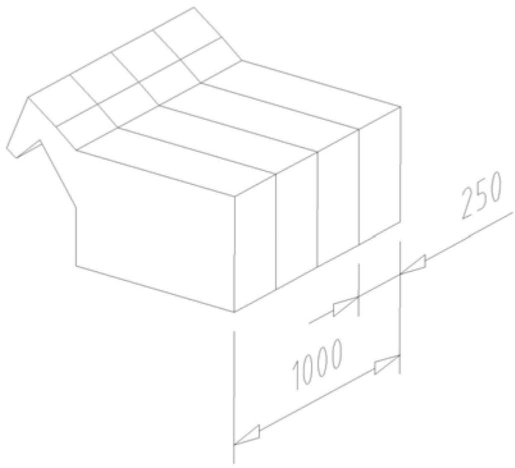

Figure 7.2 - Schematic of Sheep Model

As per Figure 7.2 each sheep modelled in the compartment represents 4 animals standing side by side. As per stocking density this equates to 16 animals per metre depth of each modelled pen. Also refer Figure 7.1.

Perimeter of modelled sheep	=	0.305m
Cross section area of side of sheep	=	$0.362m^2$
Surface area per modelled sheep	=	$(0.362m^2 \times 2) + (0.305m \times 0.25m)$
	=	$0.8m^2$
Heat Flux from surface of sheep	=	$3.2W/kg \times 40kg$
	=	128W per sheep
Area exposed to convection	=	$0.305m \times 0.25m$
	=	$0.076m^2$
Convection surface area	≈	10% of total surface area per sheep
Heat Flux from exposed surface	=	12.8W per animal
Heat Flux from animals side by side	=	$4 \times 12.8W$
	=	51.2W
Heat Flux per m^2	=	$\dfrac{15.2W}{0.305m^2}$
	=	$168W/m^2$

7.6.2 - Heat Transfer Coefficient at Ship Side

Due to one side of the compartment being bounded by the side of the vessel it was necessary to estimate a heat transfer coefficient for the heat transfer to or from the atmosphere through the side of the vessel.

As per Table C.1 in Appendix C,

Maximum free stream velocity, U_∞ = 5 m/s

Height of compartment at ship side = 2.45m

Depth of compartment, D = 1m

For Dry Air at 13.5°C,

Kinematic Viscosity, ν = 15.115×10^{-6}m²/s

Thermal Conductivity, k = 0.02465W/m.K

Reynolds Number, Re_D = $\dfrac{U_\infty D}{\nu}$

$$= \frac{5m/s\times1m}{15.115\times10^{-6}\,m^2/s}$$

$$= 330797$$

For flow normal to a flat plate,

Nusselt Number, $\overline{Nu}_D$ = $\dfrac{\bar{h}_c D}{k}$ = $0.20(\mathrm{Re}_D)^{2/3}$

$$= 0.20(330797)^{2/3}$$

$$= 956.62$$

Heat Transfer Coefficient, $\bar{h}_c$ = $\dfrac{\overline{Nu}_D \times k}{D}$

= $\dfrac{956.62 \times 0.02465 W/m.K}{1m}$

= 23.58W/m².K

For Dry Air at 32°C,

Kinematic Viscosity, ν = 16.84×10^{-6}m²/s

Thermal Conductivity, k = 0.02594W/m.K

Reynolds Number, Re_D = $\dfrac{U_\infty D}{\nu}$

= $\dfrac{5m/s \times 1m}{16.84 \times 10^{-6} m^2/s}$

= 296912

For flow normal to a flat plate,

Nusselt Number, $\overline{Nu}_D$ = $\dfrac{\bar{h}_c D}{k}$ = $0.20(\mathrm{Re}_D)^{2/3}$

= $0.20(296912)^{2/3}$

= 890.1

Heat Transfer Coefficient, $\bar{h}_c$ = $\dfrac{\overline{Nu}_D \times k}{D}$

= $\dfrac{890.01 \times 0.02594 W/m.K}{1m}$

= 23.09W/m².K

8 - Results

This section looks at the post processing phase of the analysis and the comparison of the results obtained from analysing the cases discussed earlier. In order to compare the results from the different scenarios with one another it was important to have a common point of reference.

Thus the following figures compare the temperature distribution within the compartment at a height of 1m above the deck. This height was chosen as it is approximately at the height of the backs of the animals and would provide a good idea of the comfort level likely to be experienced within the compartment where it counted most.

8.1 - Effects of Air Stream Angle and Temperature Variation

Figure 8.1 provides a comparison between the temperatures at 1 metre above the deck for the measured condition indicated by 'reference-line' against the distribution when the ambient temperature rises to 32°C represented by 'reference-line-1'. As can be expected there is an upward shift in the curve however it is important to note the maximum values in this comparison. When the ambient temperature reaches 32°C the maximum temperatures within the compartment are likely to exceed 36°C closer to the exhaust outlet and areas further away from the supply air inlet. This indicates that the animals in this area will be in significant discomfort and likely to be experience the effects of heat stress if the conditions prevail for any extended period of time.

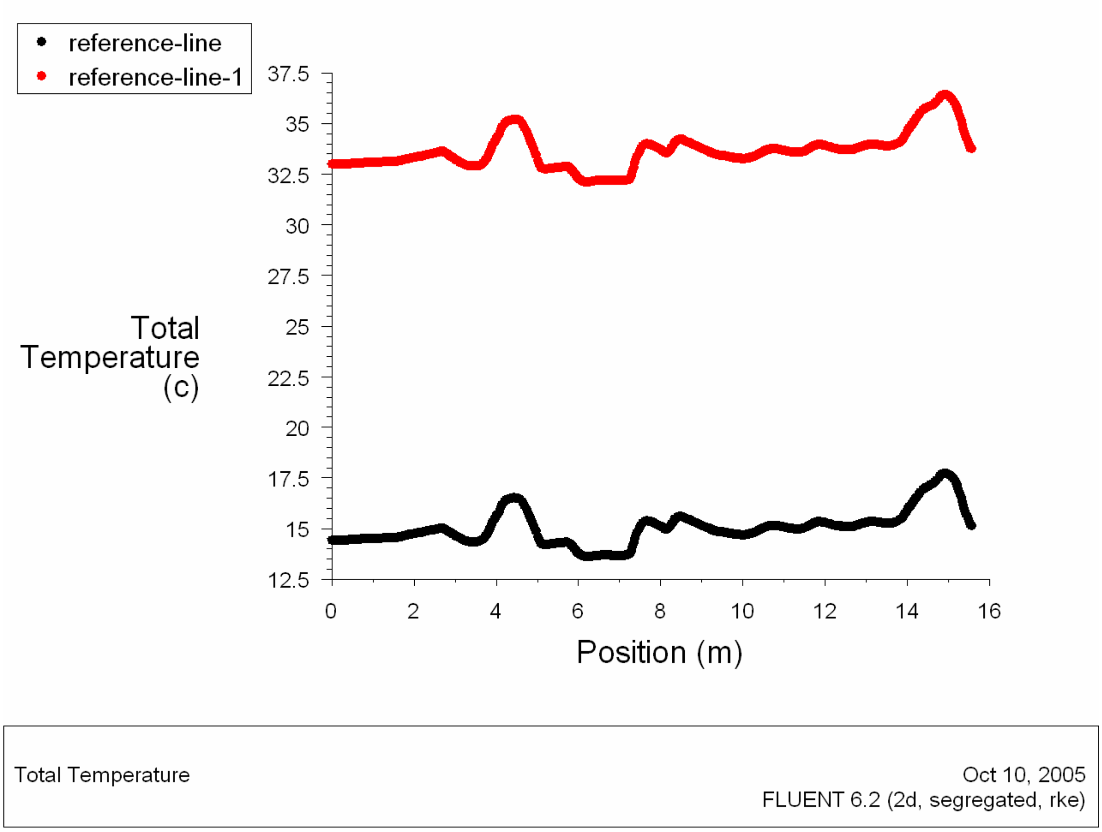

Figure 8.1 - Temperature – 13.5°C vs. 32°C Ambient Air

The next stage in the analysis was to look at how best this maximum value could be reduced by varying the angle of the supply air within the compartment as a first step. As mentioned in the description of the ventilation arrangement, the supply inlet opening features baffle plates which angle the flow of air into the compartment.

Therefore by varying the angle of these baffle plates it possible to change the resultant of the air stream entering the compartment. The existing arrangement has the baffle plates at an angle of 45° and the temperature distribution when the ambient air temperature is 32°C is shown by 'reference-line-1' in Figure 8.2. 'refence-line-2' and 'refence-line-3' indicate the effect for 60° and 30° air stream angles respectively. As the comparison shows the 30° angle resulted in lower temperatures right across the compartment while the 60° angle caused the opposite effect and resulted in elevated temperatures.

By looking at the Velocity Contour Plots in Appendix G for the corresponding cases, it can be observed that the 30° angle displayed higher air velocities further away from the supply air inlet unlike the 60° angle, which merely directed the air stream towards the deck in the immediate vicinity of the supply column.

Therefore the net result for the 30° angle was a 3% reduction in the maximum and a generally lower temperature right across the compartment compared to the existing 45° angle. The 60° angle produced an unfavourable result and was not considered any further.

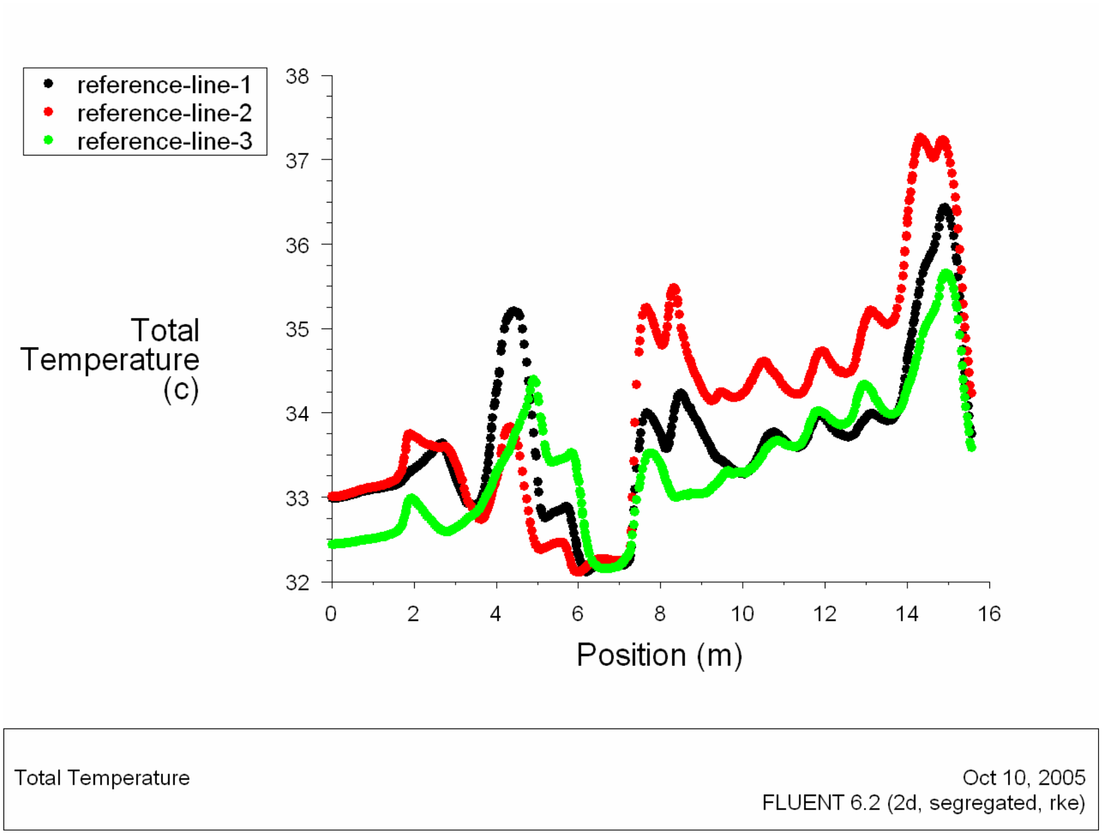

Figure 8.2 - Temperature Distribution –Varied Supply Air Stream Angles

8.2 - Effects of Supply Air Velocity Variation

Having established that varying the supply air stream angle would produce a favourable result another parameter could possibly be varied on board the vessel is the supply air velocity and thus the effect of a modest 2m/s increase in supply air velocity was analysed in conjunction with the results of the air stream angle variation. Figure 8.3 provides a comparison of a 2m/s increase in velocity at 32°C ambient air temperature and for a 30° air stream angle. ‘reference-line-3’ provides the temperatures for the existing supply air velocity and ‘reference-line-4’ that of the increased velocity. The result showed that a 2m/s increase would produce a further 2% reduction in the maximum temperature experienced in the compartment and also a steady reduction in the temperature right across the compartment including the greatest reductions in the danger area closer to the exhaust outlet where temperatures are consistently higher in all cases investigated

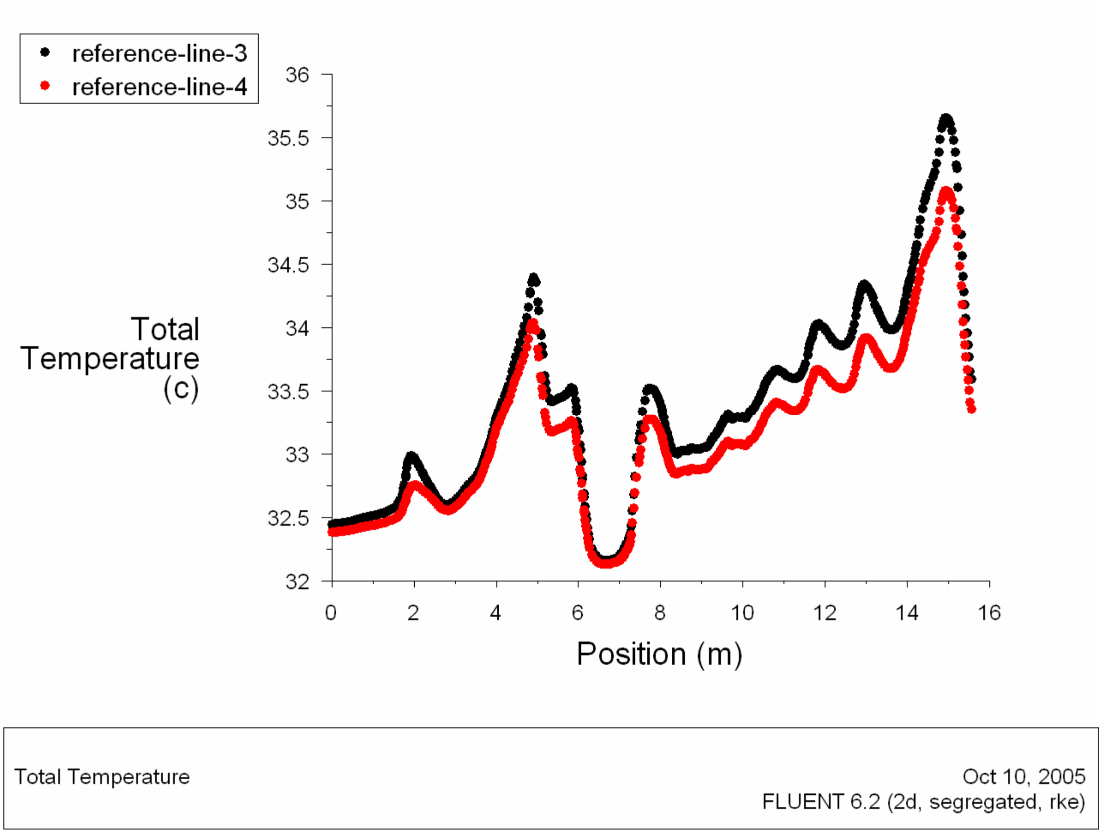

Figure 8.3 - Increased Supply Air Velocity at 32°C Ambient Air Temperature

Figure 8.4 therefore contrasts the net result of the increased supply air velocity and 30° air stream angle shown by ‘reference-line-4’ to that of the existing arrangement shown by ‘reference-line-1’ both at the 32°C ambient air temperature. The effect of varying both the angle and velocity of the supply air was a 5% reduction in maximum temperature and consistently lower temperatures of similar magnitude right across the compartment.

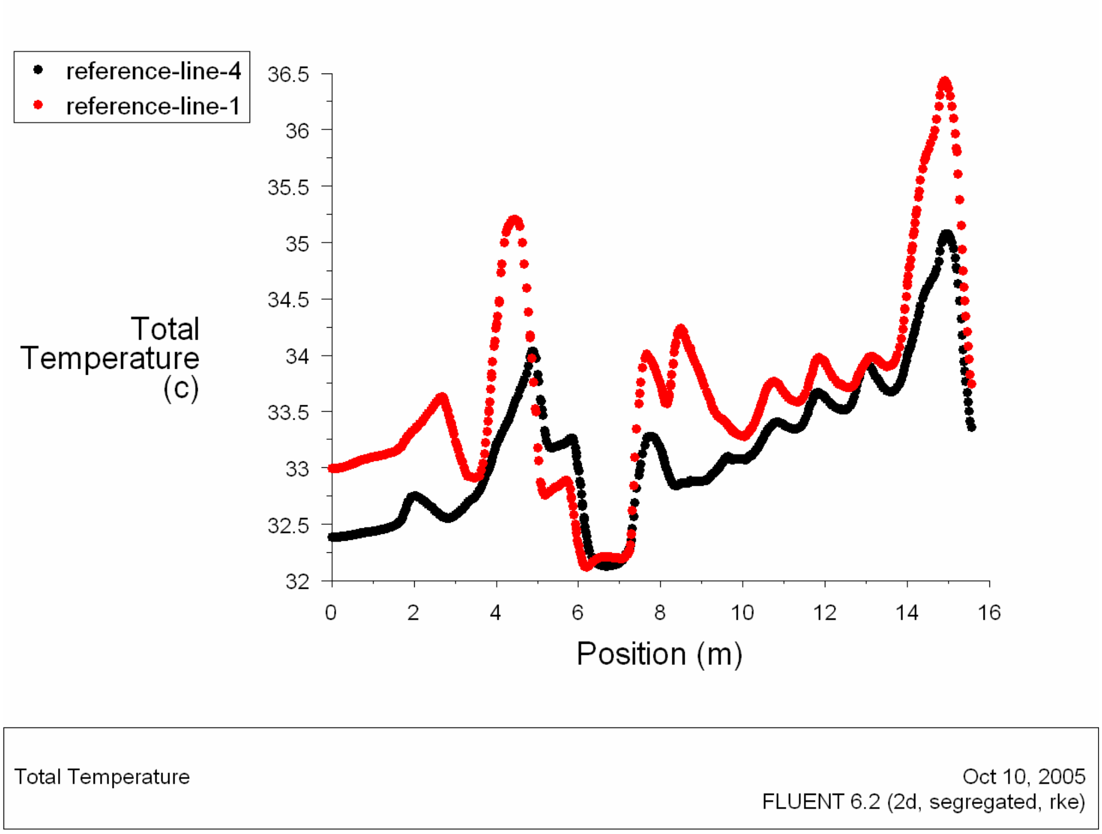

Figure 8.4 - Increased Velocity and 30° Air Stream Angle vs. Existing

Figure 8.5 displays the effect of the two variations individually against that existing arrangement. ‘reference-line-4’ shows the revised air stream angle as well as the increased supply air velocity. 'Reference-line-5' is an increase in air velocity only and 'refernce-line-1' is the existing arrangement.

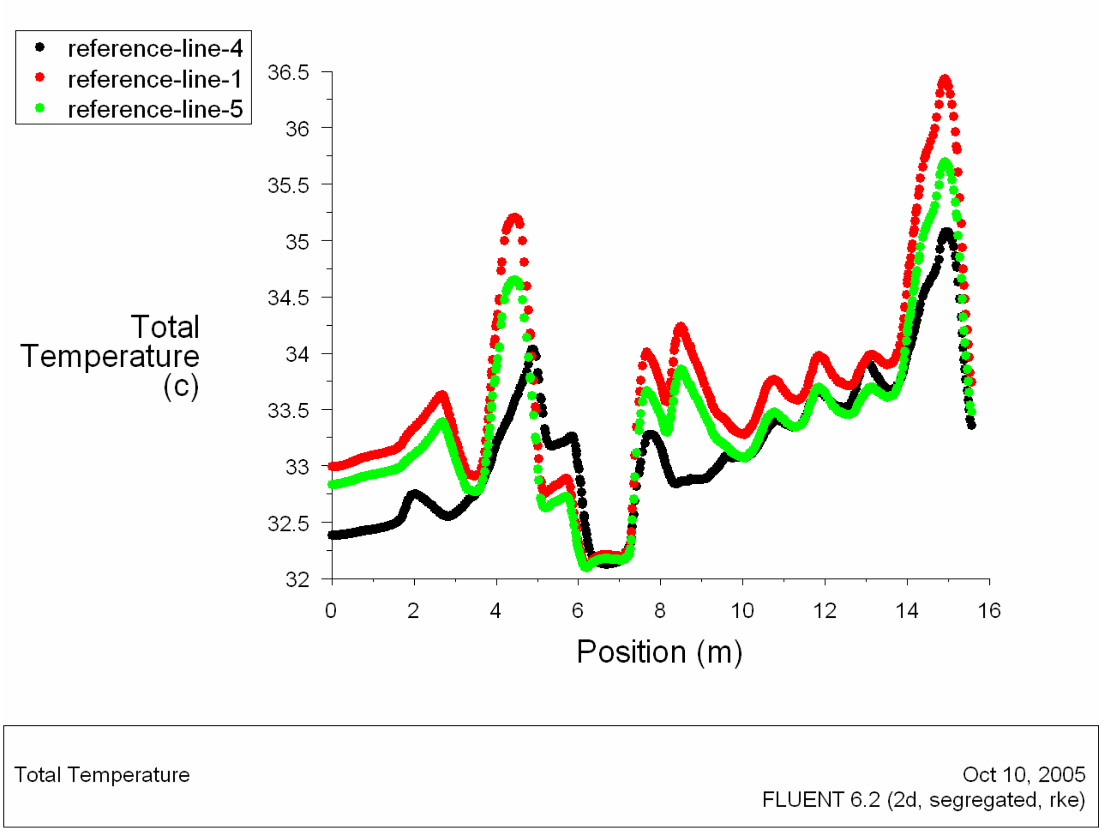

Figure 8.5 - Varied Parameters against Existing Arrangement

8.3 - Errors

In order to interpret the results of the analysis it also important to note that there were a number of difficulties faced in creating a simulation that completely replicated the physical model.

During data gathering, readings of the exhaust air velocities were taken at the outlet of the exhaust column however the velocities obtained in the FLUENT model were consistently higher at the exhaust outlet in all cases. The reason for this can be attributed to defining the exhaust outlet boundary condition as a pressure outlet with a gauge pressure of zero and fluent maintaining a mass balance within the domain with two inlets and only one outlet. Also in reality the supply and exhaust columns are staggered within the compartment and the effect of this separation could not be replicated in a 2D model.

In addition to the velocities, the temperatures of the exhaust air in the FLUENT model at the exhaust outlet also did not accurately replicate the readings taken during the data gathering stage to some extent. The temperature at the lower corner of the outlet was similar to the measured values but the centre and upper areas of the outlet displayed much lower temperatures.

In analysing the results of the simulation it is therefore important to note that a 2D analysis will provide us with a good indicative representation of the trends that can be expected however in order to completely replicate the physical model a more complex 3D analysis would be required.

9 - Conclusions

The following findings and recommendations can be put forward from this investigation.

9.1 - Project Findings

By comparing the results of the various cases analysed the following conclusions can be drawn from this investigation.

The compartment model displayed the potential for a significant build up of heat towards the outboard sides of the compartment in the immediate vicinity of the exhaust outlet. In the event that the ambient air temperatures rise to that of the simulated values, there is no doubt that animals in this area will be in significant discomfort and in danger of perishing.

By varying the angle of the supply air stream it was possible to achieve a higher distribution of air velocities further across the compartment and this resulted in lower temperatures through a more efficient removal of heat. Also by further increasing the supply air velocities there was a further reduction in temperatures within the compartment.

Therefore it can be concluded that higher localised air velocities will in fact contribute to maintaining a more habitable environment in extreme conditions. While bulk volume and the mass of air supplied to a compartment are specified as importance in providing for the welfare of livestock, the air velocity also has a significant contributory effect in maintaining lower temperatures and comfort levels within a livestock compartment.

9.2 - Recommendations

While this investigation has been limited in scope to a certain extent the following recommendation can be put forward for the purpose of further investigation and possible improvement of the ventilation arrangement aboard the livestock vessel MV Becrux.

- A more detailed 3D model to further study and analyse the efficiency of the ventilation system aboard the vessel taking into account the longitudinal separation of the supply and exhaust fans and also the effects of humidity within the compartment.

- Modifying the supply air column baffle plates to direct air further across the compartment can have a noticeable effect on the removal of heat from the compartment as proven in the simulation.

- A more comprehensive solution however would be to provide a series of branch ducts from the supply air column that will provide localised jetting of air towards the outboard areas of the compartment.

It is understood that implementing changes to the vessel is entirely at the discretion of the operators and that making significant changes to the existing ventilation system is not economically viable however the author is confident that the suggested improvements will see an economic benefit in terms of lower mortalities due to heat stress and also a better habitat to sustain the health of the animals while in transit.

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Appendix A

Project Specification

University of Southern Queensland

Faculty of Engineering and Surveying

ENG4111/2 Research Project

PROJECT SPECIFICATION

For: Jeremy Paul Outschoorn (0011123170)

Topic: Computational Fluid Mechanics investigation for aeration of ships used to transport cattle overseas

Supervisor: Dr. Ruth Mossad

Project Aim: To reduce mortality rates aboard Livestock Carriers through improved thermal habitat and ventilation design.

Programme: Issue A, 21 March 2005

1. Research background information regarding ventilation system design aboard livestock carriers. Literature search for work done in this area.

2. Site visit aboard a Livestock Carrier to gather information on ventilation systems used, and problems faced.

3. Analyse existing ventilation system and gather real time data if possible.

4. Model existing system using FLUENT CFD software and compare with real time data gathered (if available)

5. Vary parameters to see the effect on the performance of existing system

6. Present results, discussion and conclusion to recommend ways to improve the current system.

As time permits:

1. Implement change of parameters on existing system.

2. Analyse real time results.

Agreed:

_______________________________ (Student) __________________________

(Supervisor)

____/____/____ ____/____/____

Appendix B

AMSA Marine Orders Part 43 - Cargo 7 Cargo Handling Livestock

Appendix 4 - Provision of Livestock Services

Appendix 4

Provision of livestock services

1 General

Provision 12 provides that a ship permanently equipped for the carriage of livestock must be fitted with systems and equipment that ensure the maintenance of livestock services at a level necessary for the welfare of the livestock. Compliance with this Appendix will meet this requirement.

However, as an alternative, an operator may demonstrate adequate redundancy in systems and equipment by supplying to the Chief Marine Surveyor a risk analysis of the systems involved. In particular, ships constructed on or before 31 December 2001, or for which application is made for an Australian Certificate for the Carriage of Livestock before 31 December 2001, may until the end of 2006 meet the requirement by complying with provisions 13, 14 15, 16, 19 and 20 of Issue 4 of Marine Orders Part 43 (as applied by provisions 2.2.3, 2.2.4 and 2.2.5 of that Issue).

2 Sources of electrical power for livestock ships.

2.1 Main source

The ship's main source of power, as defined in Regulation 41 of Chapter II-1 of SOLAS should, in addition to being able to supply the services defined in Regulation 40.1.1 under the conditions specified in Regulation 41, be able to supply power to the livestock services under those same conditions.

2.2 Secondary source

The secondary source of power should meet the following:

(a) it should be located in a space that is not contiguous with any space containing the main source of power or part thereof, and be independent of any services provided from or through any such space;

(b) the prime mover should be capable of being started readily by an effective arrangement powered by an independent source of energy. The independent source of energy should have sufficient capacity to be able to fully recharge the starting arrangement within 30 minutes;[47]

(c) it must be capable of supplying power to livestock services for a period of three days in case of a fire or other casualty in any space containing the main source of power or any part thereof.

(d) it must at all times be maintained in a condition acceptable to the ship's classification society;

(e) the secondary source of power, all associated ancillaries and electrical systems associated with livestock services should comply with Regulation 45 of Chapter II-1 of SOLAS and meet the requirements of the ship's classification society for electrical systems; and

(f) instructions should be provided for the changeover between main and secondary sources of power and vice-versa. A copy of such instructions should be posted in the space containing the livestock source of power, and should be readable under the emergency lighting required by Regulation 43.2.2 of Chapter II-1 of SOLAS. The instructions should detail, among other things, starting method, switchboard changeover and electrical supply changeover to livestock services.

3 Ventilation

3.1.1 An enclosed space for the carriage of livestock should be provided with a mechanical ventilation system of sufficient capacity to change the air of that space in its entire volume as follows:

(a) if the minimum clear height of the space is 2.30 metres or more, not less than once every three minutes;

(b) if the minimum clear height of the space is 1.80 metres, not less than once every two minutes;

(c) if the minimum clear height of the space is between 2.30 metres and 1.80 metres, at a rate proportional to those specified above.

3.1.2 For the purposes of 3.1.1, the volume of an enclosed space includes all that space contained between the ship's side plating, bulkheads, tank top or decks enclosing the space, less the volume of any tanks or trunks that are airtight within the space and no deduction is to be made in respect of space occupied by livestock, pens

[47] The emergency source of power required by SOLAS II-1/43.1.1 may be used to power the starting arrangement in accordance with SOLAS II-1/43.1.4 provided that the emergency source of power at all times complies with SOLAS II-1/43.2 and the ship's Classification Society approves the arrangement.

or other livestock fittings.

3.2.1 A space for the carriage of livestock that is not enclosed should be provided with a mechanical ventilation system if:

(a) the space, being a structure having an arrangement of pens on more than one deck level, has a breadth greater than 20 metres; or

(b) because of a partial enclosure of the space, the natural ventilation is restricted.

3.2.2 On ships constructed or converted on or after 27 May 2004, any mechanical ventilation system referred to in 3.2.1 should be capable of providing 100 per cent of the relevant capacity in 3.1.1. On all other ships, any mechanical ventilation system referred to in 3.2.1 should be capable of providing 75 per cent of the relevant capacity in 3.1.1.

3.2.3 In determining capacity for the purpose of 3.2.2, the volume of a space referred to in 3.2.1 includes all that space contained between the extremities of a pen structure including passageways on the outboard sides or ends of the structure, less the volume of any tanks or trunks that are airtight within the pen structure and no deduction is to be made in respect of space occupied by livestock, pens or other livestock fittings.

3.3 A mechanical ventilation system should distribute air so as to ensure that the whole of each livestock space is efficiently ventilated. On ships constructed or converted on or after 27 May 2004, the mechanical ventilation system should be capable of provided a minimum air velocity across any part of a pen from a source of supply of not less than 0.5 metres per second.[47a]

3.4 Appropriate measures must be taken by the operator to ensure that air supplied to livestock spaces is as clean and fresh as practicable and that adequate separation measures are taken to ensure minimal recirculation of intake and exhaust air. Exhaust air outlets must be sited clear of the accommodation.[48]

3.5 Ventilators serving livestock spaces must remain open in all weather conditions while livestock are on board.[49]

[47a] A lower air velocity may be accepted in some areas of the pen where a solid structure or the ship's side impedes the immediate flow. However, these areas should not exceed 4% of the area of any pen.

[48] The use of a vertical high velocity exhaust system may aid in the reduction of the recirculation of exhaust and intake air.

[49] The Load Line Convention requires ventilators serving spaces below the freeboard deck, or serving enclosed superstructure decks, which can be left open in all weather conditions to be at least 4.5 metres above the deck if situated on exposed superstructure decks within L/4 from the forward perpendicular, exposed freeboard decks and raised quarter decks, and at least 2.3 metres above if situated elsewhere.

3.6 If a mechanical ventilation system is fitted, adequate spare parts[50] should be carried on the ship to enable the replacement of defective fans.[51]

3.7 In order to achieve an adequate level of redundancy, it is suggested that fan group starter panels be located in at least two locations, with the operation of fans from either panel being able to effectively ventilate the required livestock spaces. Electrical supplies from both main and secondary sources of power should be supplied to each group starter panel, with both supplies being as widely separated as practicable and neither passing through any space containing any part of the other source of power. Interlocks at each group starter should prevent simultaneous supply by both sources of power.

4 Lighting

4.1 Livestock spaces, passageways between pens and access routes between or to those spaces should be adequately lit.

4.2 Guidance may be obtained from Australian Standard AS1680. Generally however, a minimum lighting level of 20 lux is acceptable for areas of general movement and duties such as feeding and watering livestock, while an illumination level of 110 lux is needed for close examination of livestock.

4.3 An emergency lighting system that is automatically activated on the failure of the main electrical installation should be provided in all parts of a ship where livestock is carried, passageways between pens and access routes between or from those parts, and should be capable of giving a level of illumination of not less than 8 lux in all passageways and access routes for a continuous period of not less than 15 minutes.[52]

4.4 If fixed lighting is provided in a part of a ship above the uppermost continuous deck, that lighting must be capable of being controlled from the navigating bridge.

4.5 Light fittings must be waterproof and:

(a) of sufficient strength to resist damage by livestock; or

(b) placed beyond possible contact by livestock.

4.6 It is acceptable for ships that were permanently fitted for the carriage of livestock

[50] 'Adequate spare parts' should be interpreted as including for each type of fan: one set of bearings; one rotor or impeller; and one complete motor.

[51] If a mechanical ventilation system provides an air change in excess of that specified in this Part, fans providing that excess may be accepted in place of the spares required by 14.6, provided the distribution of air will remain efficient.

[52] The lamp casings on light fittings for the emergency lighting system should be painted red for ease of identification.

and had carried livestock from Australia before 1 July 1983 to be equipped with emergency hand lamps instead of an emergency lighting system referred to in 4.2:

5 Electrical Equipment for use in dust laden atmospheres

5.1 Areas where flammable dusts may be present (such as spaces used for the storage or handling of bulk fodder) must be classified in accordance with Australian Standard AS 61241.3 (IEC 61241-3:1997). Electrical equipment to be installed in spaces so categorised must be selected, installed, certified and maintained in compliance with Australian Standards AS 2381.1 and AS 61241.1.2 (IEC 61241-1-2:1999).

5.2 Lighting, or power points for portable lighting, in a space used for carriage of fodder in bulk, should be controlled by switches situated on the navigating bridge or at the fodder-handling machinery control station and indicator lights should be provided to show when power is supplied to the lighting or power points.

6 Drainage

6.1 Provision should be made for effectively draining fluids from each pen in which livestock is to be carried, under any expected conditions of trim by the head or by the stern, except that drainage is not required from the upper tier of sheep pens of ships constructed or converted before 27 May 2004 unless necessary to comply with 6.6 of this Appendix.

6.2 Drainage arrangements should be such that fluids drained from a pen are as far as practicable kept clear of other pens and associated working and access spaces.

6.3 A pump or eductor for a drainage tank or well should:

(a) be capable of handling semi-solid matter;

(b) evacuate the tank or well by lines other than the ship's bilge lines; and

(c) be powered from both the main and secondary sources of power.

6.4 Essential drainage tanks, wells and the top of drainage pipes in a ship should be accessible from outside livestock pens for the purpose of inspection and cleaning.

6.5 A drainage channel and the top of a drainage pipe should be covered by a strainer plate if:

(a) it is located inside a pen and could, if uncovered, cause injury to an animal; or

(b) it is located in a passageway and could, if uncovered, cause injury to a person.

This may require a holding tank to prevent accumulation of effluent in the livestock spaces while in port.[53]

6.6 For all new ships, and existing ships after 27 September 2008, a holding tank or treatment plant is to be provided, complying with Annex IV of MARPOL 73/78, to treat, store and discharge effluent in accordance with that Annex. The holding tank is to be of sufficient storage capacity:

(a) to ensure that effluent is not discharged in contravention with Annex IV of MARPOL 73/78; and

(b) to retain on board all effluent generated while the ship is in areas for which discharge is prohibited, such as in port and within 12 nautical miles of nearest land.[53a]

6.7 For the purpose of 6.6:

(a) an existing ship is a ship:

  (i) built or converted before 27 September 2003; and

  (ii) in respect of which an Australian Certificate for the Carriage of Livestock has been issued prior to 27 May 2004; and

  (iii) the operator of which has not changed since 27 May 2004; and

(b) a new ship is a ship that is not an existing ship.

6.8 All equipment fitted to meet the requirements of 6.6 must be capable of being operated by both the primary and the secondary sources of power.

7 Fodder & Water

7.1 The quantity of fodder and water to be provided on a ship should meet the following requirements:[53b]

(a) for cattle, buffalo, sheep and goats—the minimum requirements in the Australian Livestock Export Standards; and

[53] Effluent or effluent contaminated water must not be intentionally discharged from a ship while the ship is within the limits of an Australian port.

[53a] For the purposes of plan assessment, the effluent produced will be assumed to be the total of fodder consumption and the water consumption based on the daily allowance for the maximum expected time for the ship to be operating in waters for which discharge is prohibited.

[53b] The quantity of fodder and water to be provided on a ship should meet the minimum requirements in the Australian Livestock Export Standards for the maximum length of voyage to be undertaken by the ship.

(b) for other species—sufficient:

- for the expected period of the voyage; and
- to provide a reserve of a further 25 per cent or three days' requirements, whichever is the less.[54]

7.2 In assessing the quantity of water to be provided for a particular voyage, allowance may be made for:

(a) the anticipated quantity of potable water to be generated by the ship's equipment during the voyage, if evidence to the satisfaction of a surveyor is produced by the master attesting the capacity and efficiency of the fresh water generator; and

(b) the taking on board of a quantity of potable water at an intermediate port nominated to a surveyor by the master prior to the loading of livestock, in which case the expected period of the voyage for the purposes of 7.1 must extend from the departure of the ship from the port of loading to its arrival at the intermediate port.

7.3 A storage and efficient distribution system should be provided to supply fresh drinking water to livestock at all times while livestock are on board. If it is an automatic system, it should be so constructed as to:

(a) minimise, by control of the level of water, any spillage from a receptacle; and

(b) prevent the return of water from a receptacle to the freshwater tank.

7.4 The master should ensure that each tank used for the storage of drinking water for livestock is maintained in good condition to ensure that the water is not contaminated.

7.5 In order to achieve a satisfactory level of redundancy, the following are required:

(a) the water reserve referred to in 7.1 and the Australian Livestock Export Standards should be available from the ship's tanks, but may include the output from a fresh water generator, provided it can be powered by both the main and secondary sources of power and can continue to operate despite a fire or other casualty in the space containing the main source of power;

(b) at least two pumps for distribution of water supplies should be provided. One may be located in the space occupied by the main source of power and supplied by that source of power. The other should be able to maintain supply despite a

[54] For the issue of an ACCL the ability of a ship to provide the water reserve from the ship's tanks will be assessed on the basis of a requirement of 36 litres per square metre of pen area per day for cattle and 6 litres per head per day for sheep.

fire or other casualty affecting the space occupied by the main source of power; and

(c) if the fodder distribution system is dependant on electric power, the system must be capable of being powered by both the main and secondary sources of supply.

7.6 Fodder in pelletised or other concentrated form supplied to a ship for the purposes of 7.1 should be accompanied by a certificate from the pellet manufacturer stating the average temperature and moisture content of the pellets as delivered alongside the ship and certifying that the pellets were manufactured in accordance with the National Pellet Standards issued by the Livestock Exporters' Industry Advisory Council.

7.7.1 The Master should ensure that fodder is not placed on the floor of a pen, stall or similar fitting containing livestock.

7.7.2 Each pen, stall or similar fitting should be provided with receptacles for feeding and watering of livestock and, except where the fodder or water is provided by an automatic system, the receptacles must be capable of containing at least 33 per cent of the daily allowance of fodder[54a] and water[54b] for the number of animals contained in the pen, stall or fitting.

7.7.3 A feeding receptacle is not required for a pen containing cattle, provided:

(a) the pen adjoins a passageway and the cattle can conveniently consume hay distributed on the floor of the passageway; and

(b) urine, faeces and water used in washing any pen is prevented from fouling the passageway.

7.8.1 A receptacle provided in accordance with 7.7.2 should be:

(a) suitable for the species of livestock;

(b) readily accessible to the livestock;

(c) capable of being serviced from outside the pen, stall or other fitting;

(d) so installed as to not impede ventilation; and

(e) so constructed and positioned, that fodder dust is not disturbed by the flow of ventilation.

[54a] For the purposes of approval of the receptacle only, the daily allowance fodder is to be taken as 5.7kg per m^2 of pen space for cattle and 4.8kg per m^2 of pen area for sheep and goats (irrespective of age).

[54b] For the purposes of approval of the receptacle only, the daily allowance for water to be calculated on the basis of a requirement of 36 litres per square metre of pen area per day for cattle and 6 litres per head per day for sheep.

In respect of adult sheep the top of a trough used as a water or fodder receptacle should be approximately 550 millimetres above the pen floor.

7.8.2 A pipe or rounded bar should be provided in a pen where the trough is not portable in order to minimise fouling of the trough. The pipe or bar should be at a suitable height to prevent or minimise fouling of the trough and at a horizontal distance of 75 millimetres (in a pen designed for sheep) or 150 millimetres (in a pen designed for cattle) or more from the edge of the trough.

7.9 Automatic feeding and watering systems should, if practicable, be set up and capable of supplying water and fodder in accordance with this Part before livestock are loaded. Irrespective of the systems used, water and fodder should be provided to livestock not later than 12 hours after loading has commenced.

7.10 Fodder other than hay stored in bulk in a ship on which conversion or construction for the carriage of livestock commenced after 1 July 1983, should be carried in not less than two separate spaces on the ship.

7.11 The Master should ensure that fodder in storage or in feeding receptacles is kept in a dry state, protected from the weather and sea.[55]

7.12 Fodder may be stored in an enclosed livestock space if it does not interfere with the ventilation, lighting, drainage and passageway provisions of this Part. Fodder stowed on an open deck, whether on pallets, in containers or otherwise, should be secured to prevent movement prior to proceeding to sea.

* * * * * *

[55] Pelletised food is, depending on moisture content, liable to spontaneous combustion. Guide-lines cannot be given as to the level of moisture that causes this reaction in individual types of pellets. Masters and others concerned are advised to ensure that the moisture content of pellets is within the product specification and to avoid loading pellets in wet weather conditions.

Appendix C

Readings

READING NO.	1	2	3	4	5
TIME	15:00	15:45	20:00	6:00	6:30
DATE	29-Aug-05	29-Aug-05	29-Aug-05	30-Aug-05	30-Aug-05
SUPPLY AIR					
LOCATION	FR.111 (S)	FR.91(S)	FR.111 (S)	FR.111 (S)	FR.111 (S)
VELOCITY (m/s)	11.5	12.0	10.5	10.5	11.0
TEMPERATURE (°C)	17.6	18.1	16.6	13.5	13.0
RELATIVE HUMIDITY	58%	58%	63%	63%	65%
WET BULB TEMP (°C)	12.3	12.5	12.8	10.1	11
INLET SIZE (mm)	480 x 300	480 x 300	480 x 300	480 x 300	480 x 300
EXHAUST AIR					
LOCATION	FR.112 (S)	FR.95 (S)	FR.112 (S)	FR.112 (S)	FR.112 (S)
VELOCITY (m/s)	5.1	4.9	5.7	5.5	5.0
TEMPERATURE (°C)	17.8	18.0	19.8	17.2	16.8
RELATIVE HUMIDITY	60%	60%	71%	65%	70%
WET BULB TEMP (°C)	12.3	12.4	15.7	13.1	12.1
OUTLET SIZE (mm)	650 x 500	650 x 500	650 x 500	650 x 500	650 x 500
AMBIENT AIR					
WIND SPEED (m/s)	8 - 10	8 - 10	4 - 6	3 - 5	3 - 5
TEMPERATURE	17.3	17.3	16.8	13.9	13.9
RELATIVE HUMIDITY	56%	56%	60%	62%	62%
LIVESTOCK DATA					
PEN NUMBER	-	-	4-097	4-097	3-097
ANIMALS PER PEN	-	-	55 - 60	55 - 60	55 - 60
PEN AREA	-	-	17.67	17.67	17.53
BODY TEMP (°C)	-	-	25 - 27	25 - 27	24 - 26.5
BODY MASS (kg)	-	-	~40	~40	~40
COAT LENGTH	-	-	Shorn	Shorn	Shorn
BREED	-	-	Merino	Merino	Merino
ACCLIMATISATION	-	-	5 Days	5 Days	5 Days

Table C.1 - Readings

Appendix D

Instrument Specification Sheets

VELOCICALC® Plus

Multi-Parameter Ventilation Meters

Models 8384, 8385, 8386

TSI's VELOCICALC® Plus Meters simultaneously measure and data log several ventilation parameters using a single probe with multiple sensors. Based on the model, these hand-held instruments measure velocity, temperature, differential pressure and humidity. All versions calculate volumetric flowrate. The Model 8386 also performs dew point, wet bulb temperature and heat flow calculations.

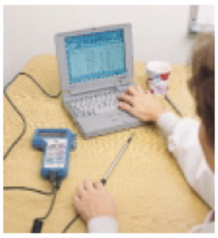
Model 8386

Data Logging Capabilities

- Data logging ability allows user to log 1394 samples with a time and date stamp
- Simultaneously records all parameters available in each model
- Single point and continuous data logging modes to fit your application
- Data can be reviewed on-screen, printed or downloaded to a computer spreadsheet program
- TSI downloading software permits easy transfer of data to a computer
- Statistics function displays average, maximum and minimum values, and the number of recorded samples

Features and Benefits

- Wide velocity range of 0 to 50 m/s
- Flowrate feature makes simple calculations of volumetric flowrate when the user inputs the duct shape and size, K factor or horn size
- Velocity measurements are made from the thermal sensor or a Pitot tube
- Automatic conversion between actual and standard velocity readings
- Direct calculation of dew point and wet bulb temperature - no psychrometric chart needed (Model 8386 only)
- Heat flow function calculates heat transferred after a heating or cooling element (Model 8386 only)
- Stable digital display when measuring fluctuating flows
- Back-lit display is easy to read in poor lighting conditions
- 101.6 cm telescoping probe with etched length marks to make duct traverse measurements easier
- Optional articulating probe available
- Optional portable printer provides hard copy documentation of your measurements



TSI®

VelociCalc Plus Specifications—Models 8384(A), 8385(A) and 8386(A)**

Velocity From Thermal Sensor (all models):
Range: 0 to 50 m/s (0 to 9,999 ft/min)
Accuracy[1&2]: ±3.0% of reading or ± .015 m/s (±3 ft/min), whichever is greater
Resolution: 0.01 m/s (1 ft/min)

Velocity From a Pitot Tube (Models 8385(A) and 8386(A)):
Range[3]: 1.27 to 78.7 m/s (250 to 15,500 ft/min)
Accuracy[4]: ±1.5% at 10.16 m/s (2,000 ft/min)
Resolution: 0.01 m/s (1 ft/min)

Volumetric Flowrate (all models):
Range: Actual range is a function of maximum velocity, pressure, duct size, and K factor

Duct Size (all models):
Range: 1 to 635 cm in increments of 0.1 cm (1 to 250 in. in increments of 0.1 in.)

Static/Differential Pressure (Models 8385(A) and 8386(A)):
Range[5]: -9.3 to +28.0 mmHg, or -1245 to +3735 Pa (-5 to +15 in. H_2O)
Accuracy[6]: ±1% of reading, ±1 Pa or ±0.01 mmHg (±0.005 in. H_2O) ±0.03%/°C (±0.02%/°F)
Resolution: 1 Pa, 0.01 mmHg (0.001 in. H_2O)

Instrument Temperature Range:
Operating (Probe-8384 (A) and 8385 (A)): -17.8 to 93.3°C (0 to 200°F)
Operating (Probe-8386 (A)): -10 to 60°C (14 to 140°F)
Operating (Electronics): 5 to 45°C (40 to 113°F)
Storage: -20 to 60°C (-4 to 140°F)
Resolution: 0.1°C (0.1°F)
Accuracy[7]: ±0.3°C (±0.5°F)

Relative Humidity (Model 8386(A) only):
Range: 0 to 95% rh
Accuracy[8]: ±3% rh
Resolution: 0.1% rh

Wet Bulb Temperature (Model 8386(A)):
Range: 5 to 60°C (40 to 140°F)
Resolution: 0.1°C (0.1°F)

Dewpoint (Model 8386(A) only):
Range: -15 to 49°C (5 to 120°F)
Resolution: 0.1°C (0.1°F)

Heat Flow (Model 8386(A) only):
Range: Function of Flow Rate, Temperature, Humidity and Barometric Pressure
Measurements Available: Sensible Heat Flow, Latent Heat Flow, Total Heat Flow and Sensible Heat Factor
Units Measured: BTU/h, kW

Logging Capability (all models):
Range: Up to 1394 samples and 275 test id's (one sample can contain up to all eleven measurement types)
Intervals: 2 sec, 5 sec, 10 sec, 15 sec, 20 sec, 30 sec, 60 sec, 2 min, 5 min, 10 min, 15 min, 20 min, 30 min, 60 min

Time Constant (all models):
Intervals: 1 sec, 2 sec, 5 sec, 10 sec, 15 sec, 20 sec

External Meter Dimensions (all models):
Size Measurements: 10.7 cm × 18.3 cm × 3.8 cm (4.2 in. × 7.2 in. × 1.5 in.)

Meter Probe Dimensions (all models):
Probe Length: 101.6 cm (40 in.)
Probe Diameter of Tip: 7.01 mm (0.276 in.)
Probe Diameter of Base: 10.03 mm (0.395 in.)

Articulating Probe Dimensions (Models 8384A, 8385A, 8386A):
Articulating Section Length: 16.26 cm (6.4 in.)
Diameter of Articulating Knuckle: 9.44 mm (0.372 in.)

Meter Weight Dimensions (all models):
Weight (with batteries): 0.54 kg (1.2 lbs)

Power (all models):
Requirements: Four AA-size batteries (included) or AC adapter (optional)

	8384	8385	8386
Velocity	•	•	•
Volumetric Flowrate	•	•	•
Temperature	•	•	•
Differential Pressure		•	•
Thermal/Pitot		•	•
Humidity			•
Dew Point			•
Wet Bulb Temperature			•
Heat Flow Calculations			•
Data Logging/Downloading	•	•	•
Statistics/Review Data	•	•	•
Density Correction Factor	•	•	•
Variable Time Constant	•	•	•
Printer Output	•	•	•
NIST* Calibration Certificate	•	•	•

All models are available with either a straight or articulating probe.

** Where 83XX(A) is listed, the specifications apply to both the 83XX (straight probe) and 83XX A (articulating probe) models.

1 Temperature compensated over an air temperature range of 5 to 65°C (40 to 150°F)
2 The accuracy statement of ±3.0% of reading or ±0.015 m/s (±3 ft/min), whichever is greater, begins at 30 ft/min through 9,999 ft/min.
3 Pressure velocity measurements are not recommended below 1,000 ft/min and are best suited to velocities over 2,000 ft/min. Range can vary depending on barometric pressure.
4 Accuracy is a function of converting pressure to velocity. Conversion accuracy improves when actual pressure values increase.
5 Overpressure range = 520 mmHg, 69 kPa (275 in H_2O)
6 Accuracy with instrument case at 25°C (77° F), add uncertainty of 0.03%/°C (0.02 %/°F) for change in instrument temperature.
7 Accuracy with instrument case at 25°C (77°F), add uncertainty of 0.03°C/°C (0.05°F/°F) for change in instrument temperature.
8 Accuracy with probe at 25°C (77°F). Add uncertainty of 0.2%RH/°C (0.1%RH/°F) for change in probe temperature. Includes 1% hysteresis.

Specifications are subject to change without notice.

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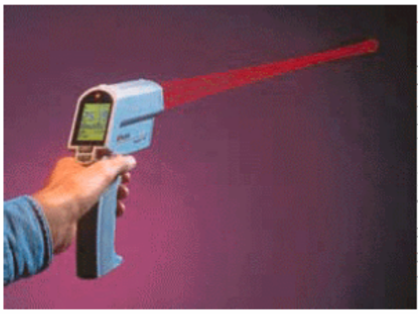
Raytek Raynger® MX™ *Series*



What you see is what you get!

Designed for ease-of-use, unmatched performance, and featuring new laser technology, the MX is the future of temperature measurement.

The new Raynger MX is the only portable IR thermometer on the market with a 16-point laser circle that shows the spot size you are measuring at any distance. No other infrared thermometer provides this circular sighting feature with a distance to spot ratio of 60:1!

Innovative Features.

- **On-board emissivity table**
- **Measures contact & IR temperature, simultaneously**
- **Customizable log location**
- **Bar graph charts last 10 temperature points**

Additional Features of MX Series

Temperature Range	-30 to 900°C (-25 to 1600°F)
D:S (Distance to Spot Size)	60:1
Laser Sighting	16-point, class 2
Emissivity	Adjustable
Accuracy	± 1%
Response Time	250mSec
°C or °F	Selectable
Protective Hard Case	Included
Data output	RS-232 or 1 mV per degree

The MX Series is available in three models, the MX2, the MX4, and MX4+. The choice depends on the user's application. The MX4+ package includes **data management software** for graphing temperature data and trend analysis.

MX Specifications

Features	MX2	MX4	MX4+	MX close- focus
Temperature Range	-30 to 900°C (-25 to 1600°F)	-30 to 900°C (-25 to 1600°F)	-30 to 900°C -250 to 1600°F)	-30 to 900°C -250 to 1600°F)
D:S (distance to spot size)	60:1	60:1	60:1	50:1
16 point laser circle spot	*	*	*	*
Adjustable Emissivity	*	*	*	*
On-board emissivity table		*	*	*
Accuracy	+/- 1%	+/- 1%	+/- 1%	+/- 1%
Response Time	250 mSec	250 mSec	250 mSec	250 mSec
MAX and MIN temperature	*	*	*	*
DIF and AVG temperature		*	*	*
Recall Last Reading		*	*	*
Data output: RS232		*	*	*
100 points data logging		*	*	*
Thermocouple K Probe			*	*
Windows-compatible Data Graphing Software			*	*

DataTemp MX Software

DataTemp MX Software is a Windows® compatible data management software for temperature graphing and trend analysis. Use this software to organize, display, and print temperature data and customize log locations. Choose one of 30 pre-set emissivity values from the built-in-table, or adjust the value to fit a specific application. Store up to 10,000 temperature measurement points using continuous or manual single-point recording. The software has programmable time intervals, temperature scales and limits, and can show both contact and infrared temperatures simultaneously.

Appendix E

Compartment Cross Section

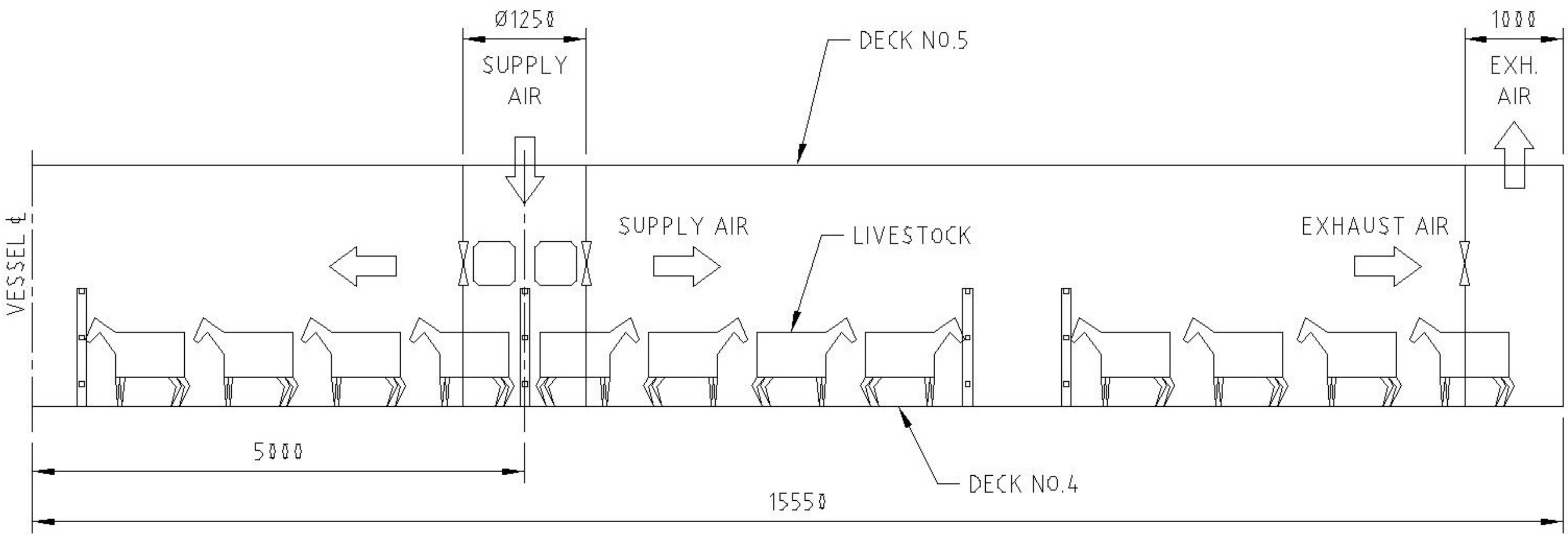


Figure E.1 – Compartment Cross Section used for GAMBIT/FLUENT Model

Appendix F

Compartment Mesh

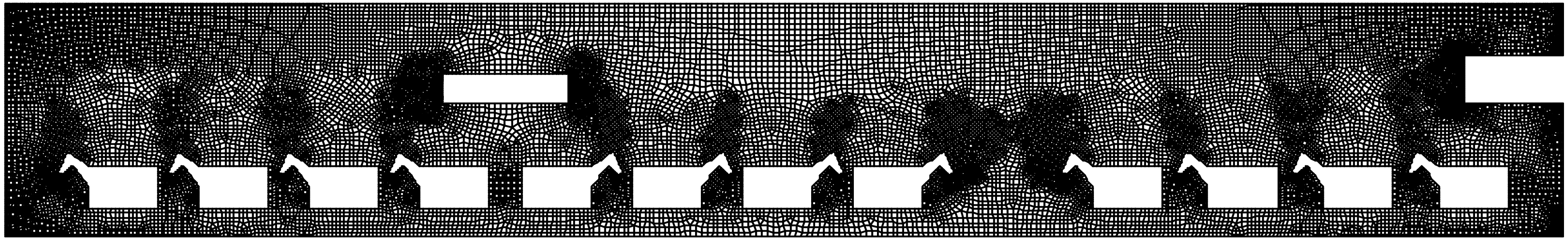
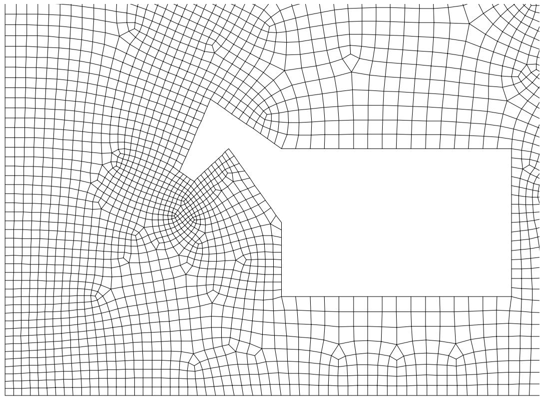


Figure F.1 – Compartment Mesh



Enlarged view of GAMBIT Compartment Mesh

Appendix G

FLUENT Contour Plots

Case 0 - Measured Condition

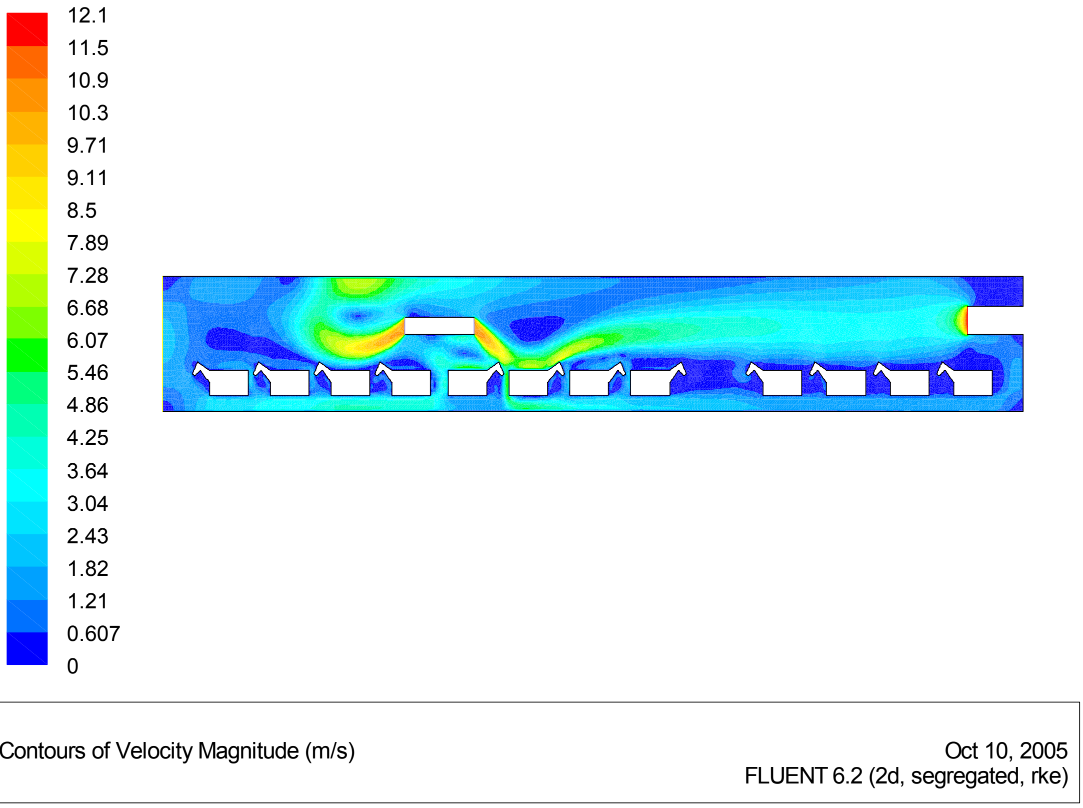


Figure G.1 – Case 0 - Velocity Contours

Velocity contours within the compartment generated for measured condition. Supply air velocity 10.5m/s, stream angle 45° from horizontal as per existing arrangement.

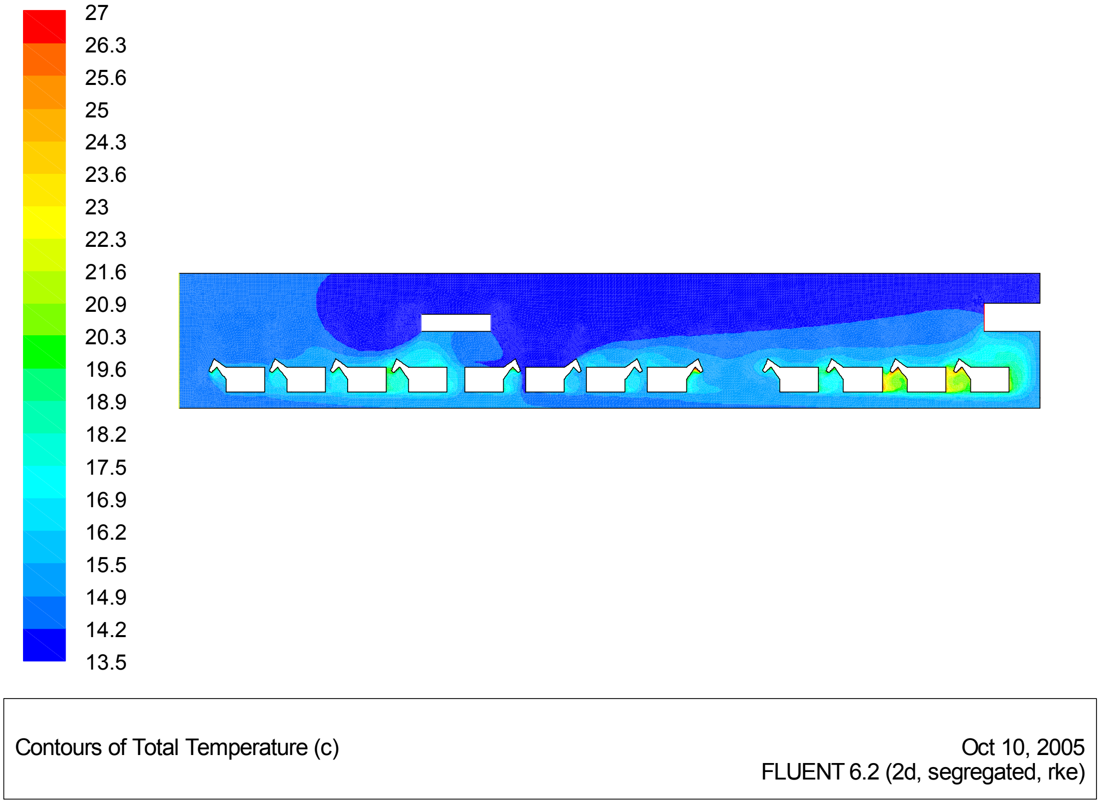


Figure G.2 – Case 0 - Temperature Contours

Temperature Contours within compartment for measured condition. Ambient air temperature at 13.5°C.

Case 1 - 32°C Ambient Air Temperature

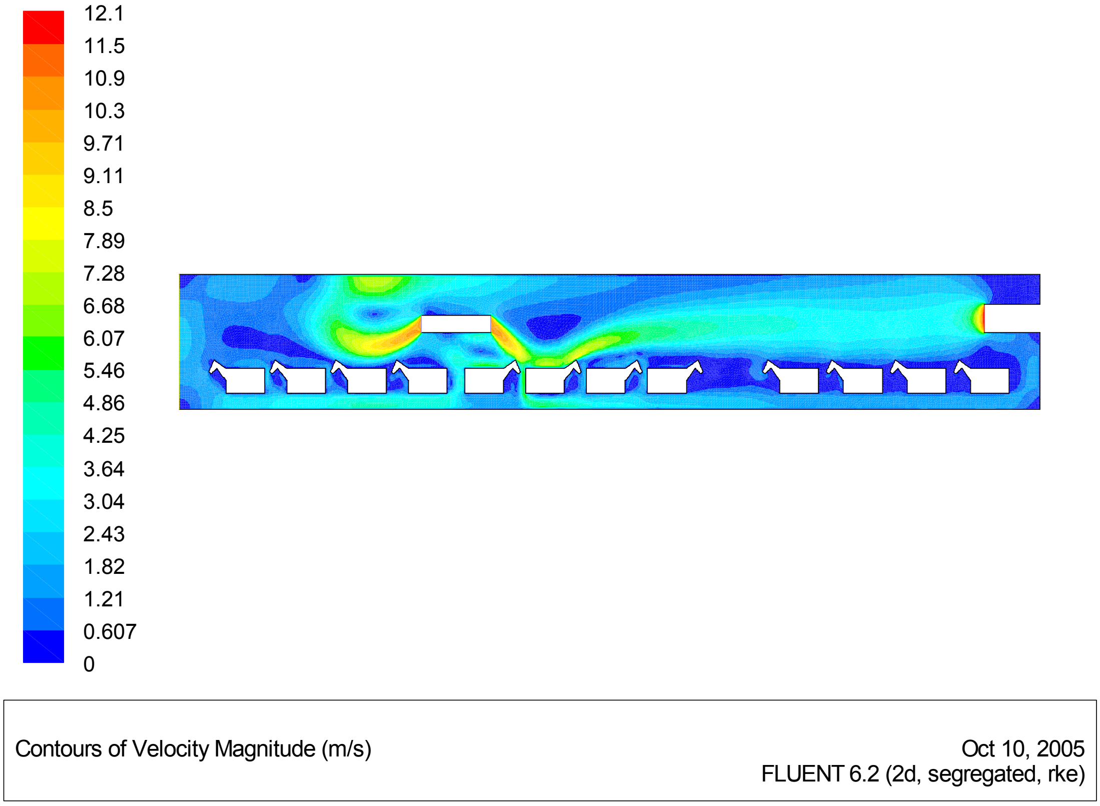


Figure G.3 – Case 1 - Velocity Contours

Velocity Contours within compartment. Supply Air Velocity 10.5m/s, stream angle 45° from horizontal as per existing arrangement.

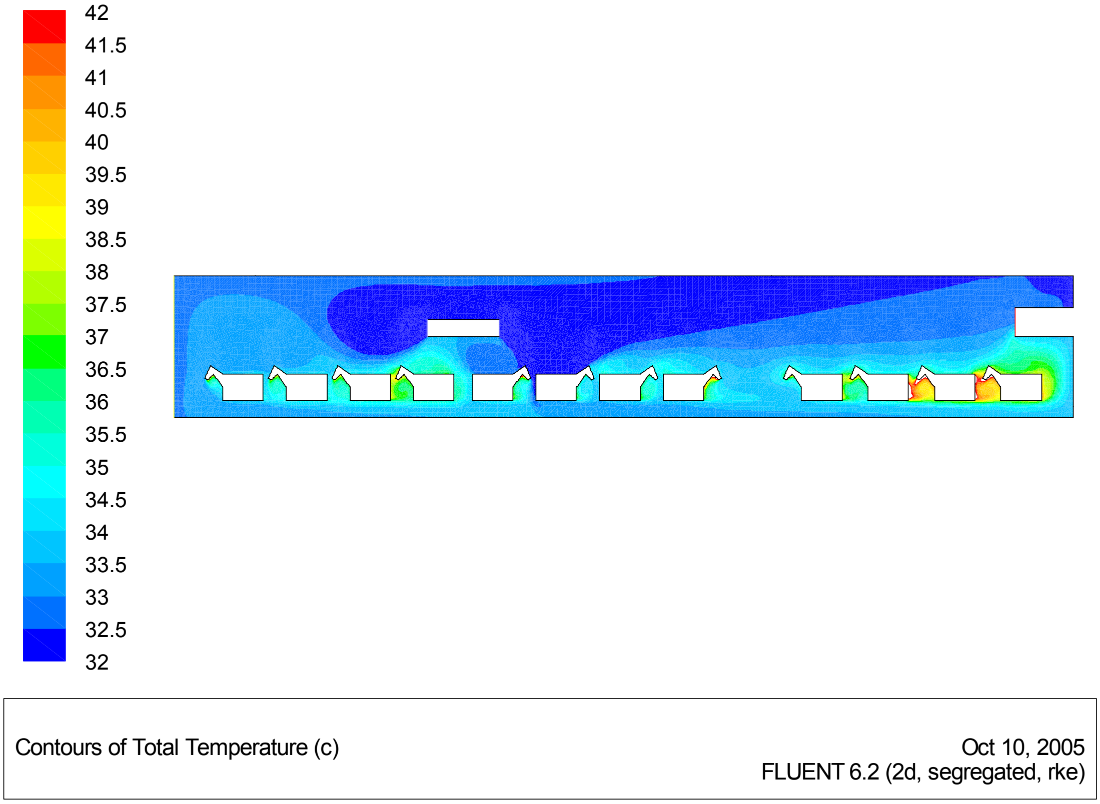


Figure G.4 – Case 1 - Temperature Contours

Temperature Contours within compartment when ambient air temperature rises to 32°C.

Case 2 - 32°C Ambient Air Temperature, 60° Stream angle

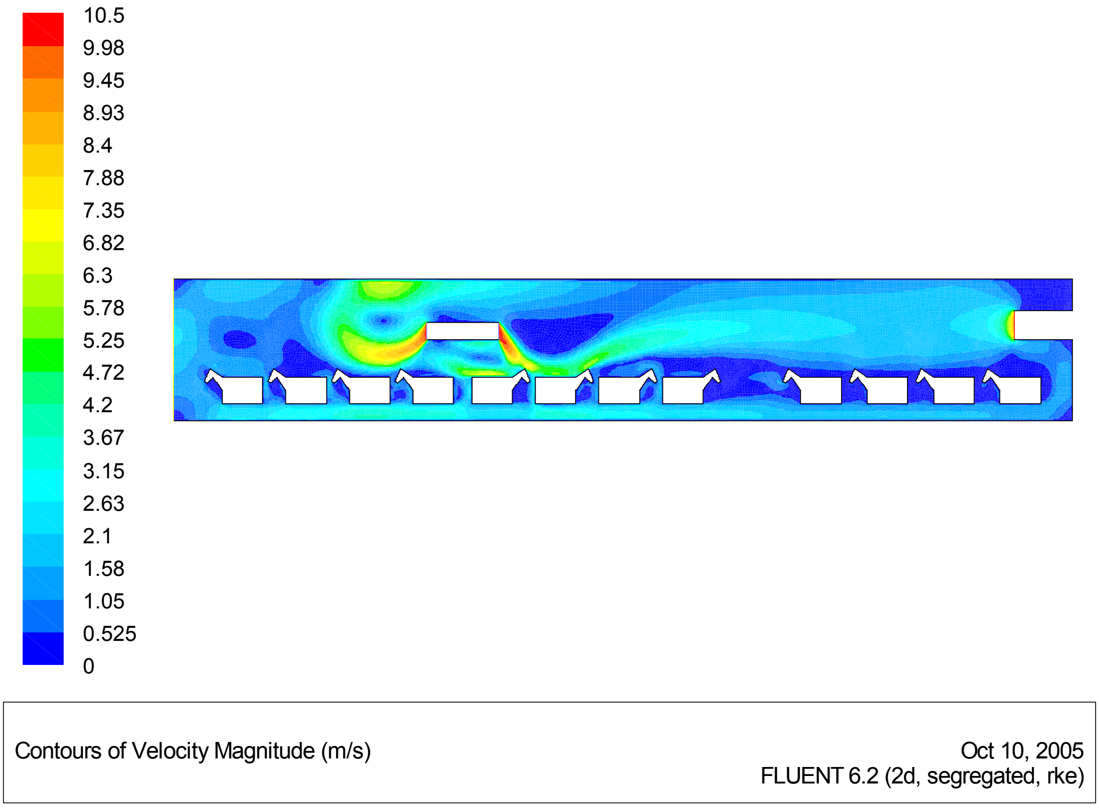


Figure G.5 – Case 2 - Velocity Contours

Velocity Contours within compartment for stream angle 60° from horizontal. Supply air velocity 10.5m/s.

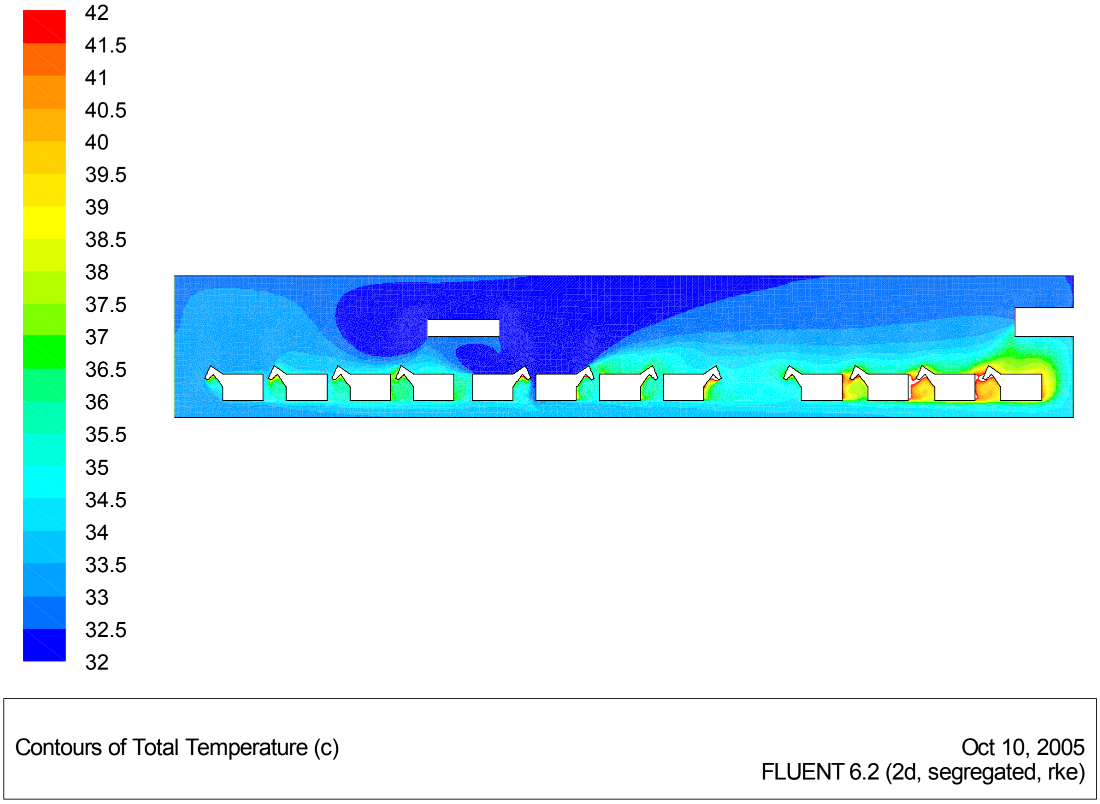
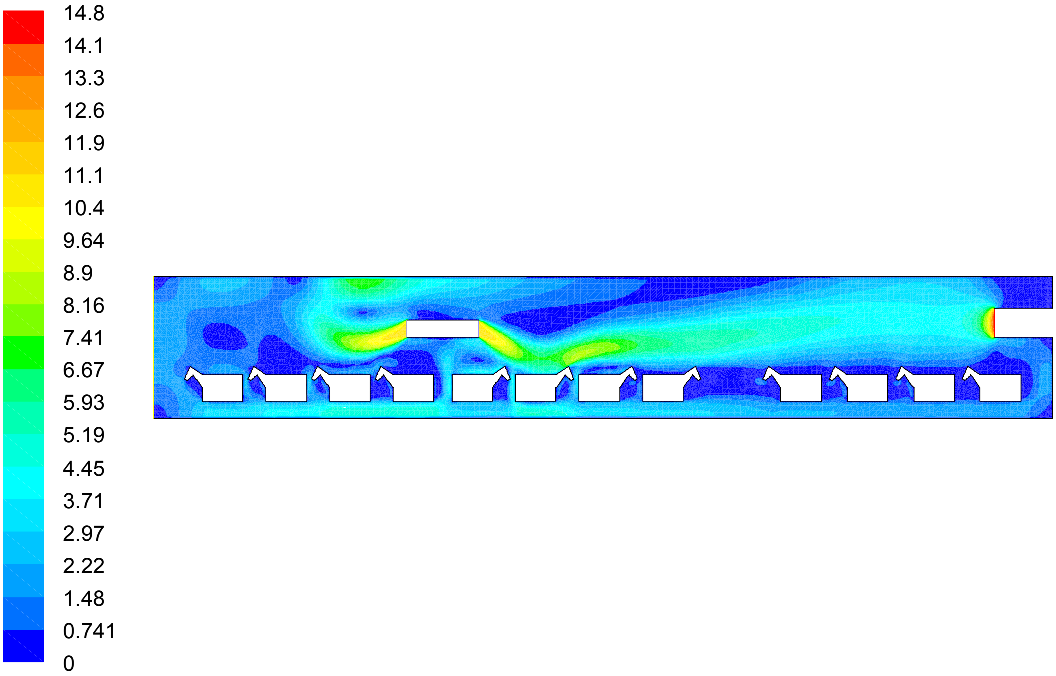


Figure G.6 – Case 2 - Velocity Contours

Temperature Contours within compartment at 32°C ambient air temperature.

Case 3 - 32°C Ambient Air Temperature, 30° Stream Angle



Contours of Velocity Magnitude (m/s)

Oct 10, 2005
FLUENT 6.2 (2d, segregated, rke)

Figure G.7 – Case 3 - Velocity Contours

Velocity Contours within compartment for stream angle 30° down from horizontal.

Supply air velocity 10.5m/s.

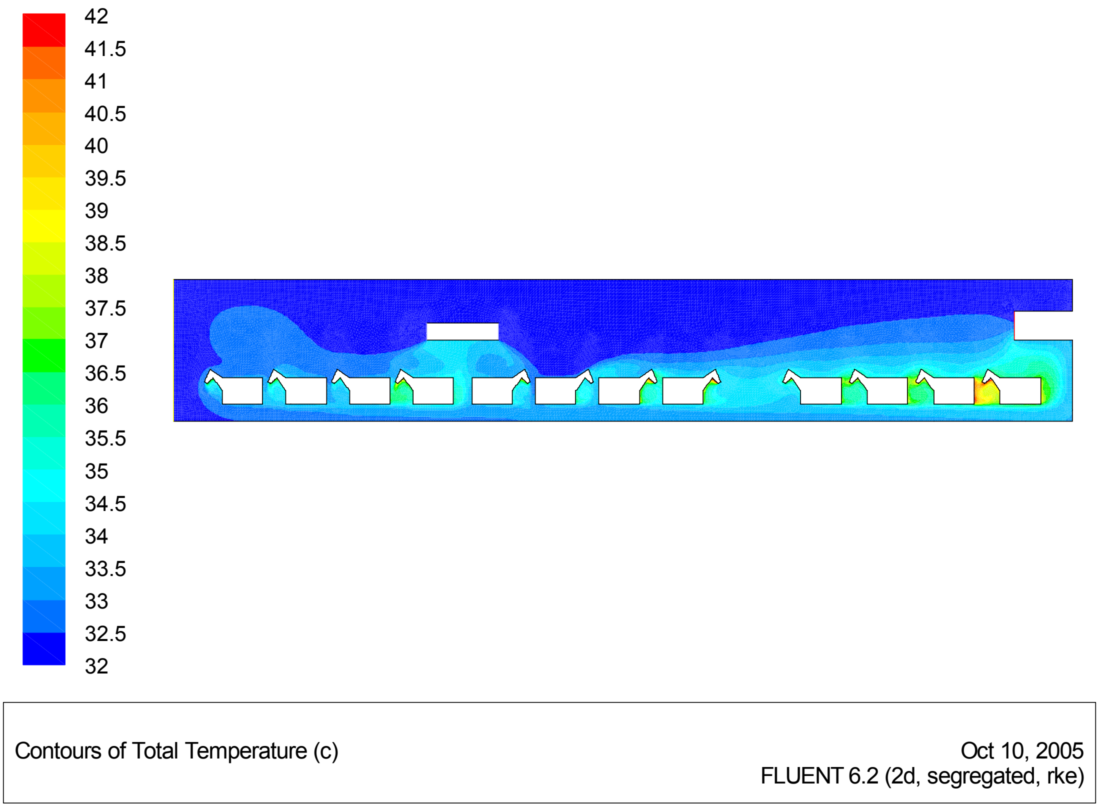


Figure G.8 – Case 3 - Temperature Contours

Temperature Contours within compartment at 32°C ambient air temperature.

Case 4 - 32°C Ambient Air Temperature, 30° Stream Angle, 12m/s Supply Air Velocity

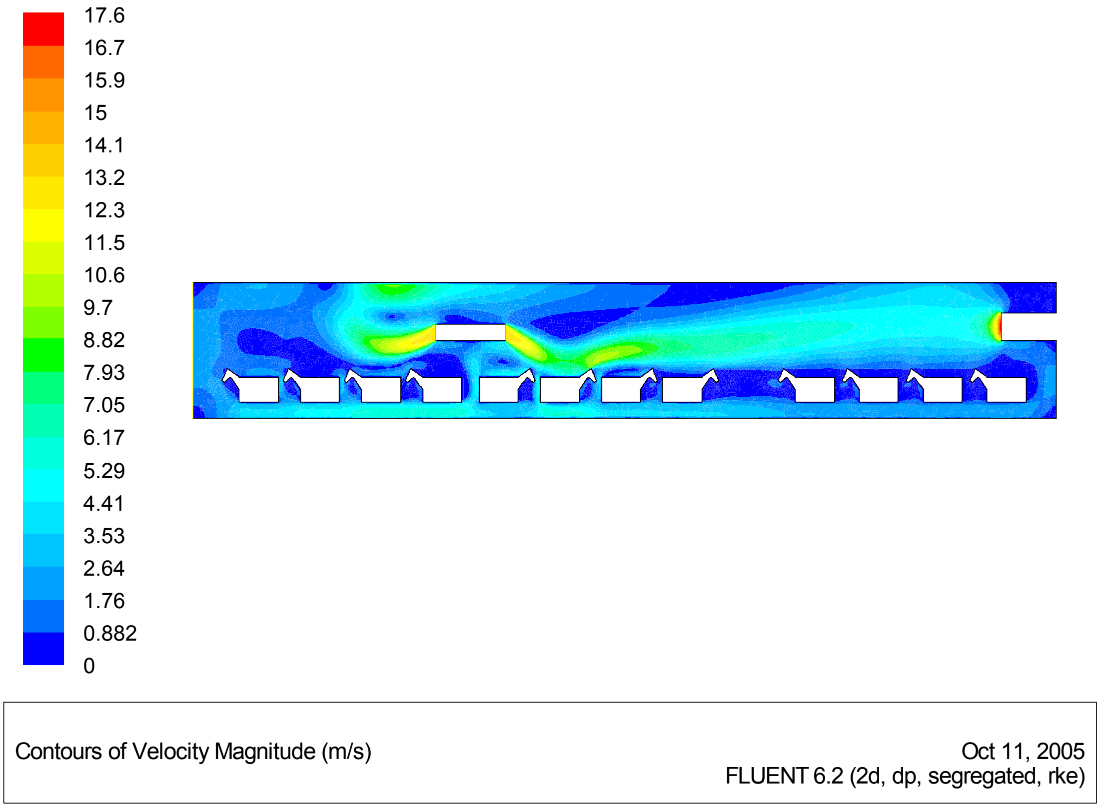


Figure G.9 – Case 4 - Velocity Contours

Velocity Contours within compartment for increased supply air velocity of 12m/s and stream angle 30° from horizontal.

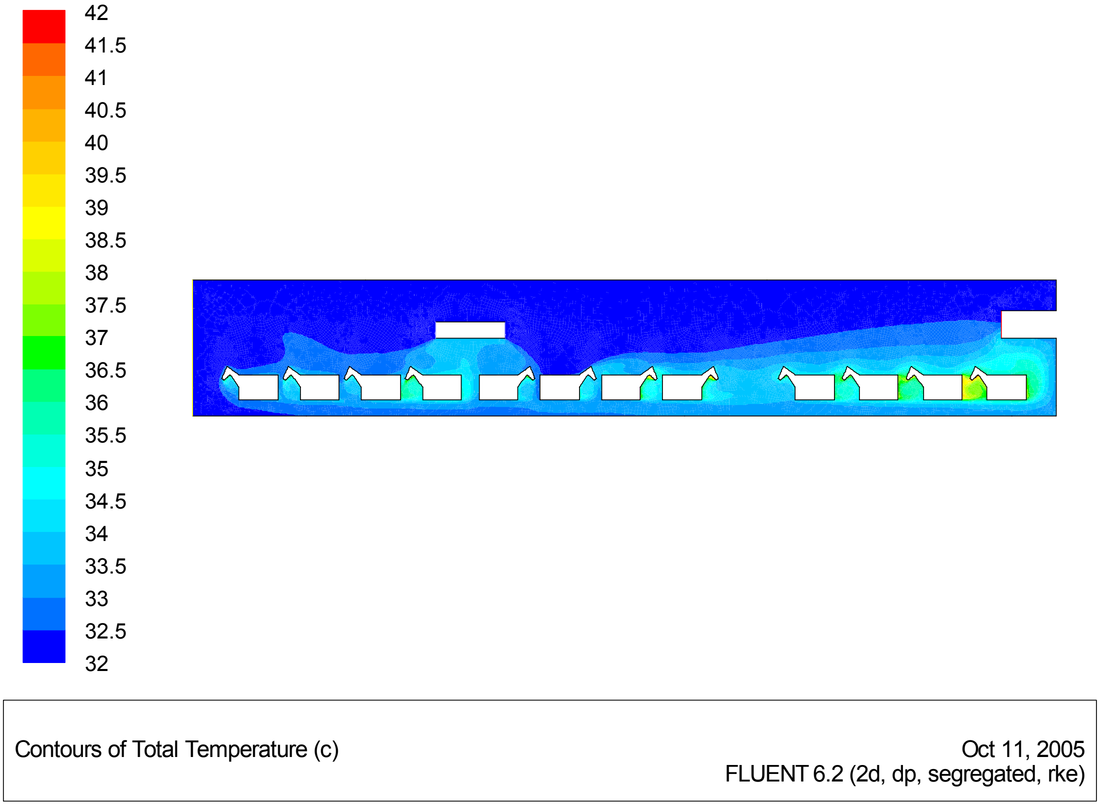


Figure G.10 – Case 4 - Temperature Contours

Temperature Contours within compartment at 32°C ambient air temperature and increased supply air velocity of 12m/s.

Case 5 - 32°C Ambient Air Temperature, 45° Stream angle, 12m/s Supply Air Velocity

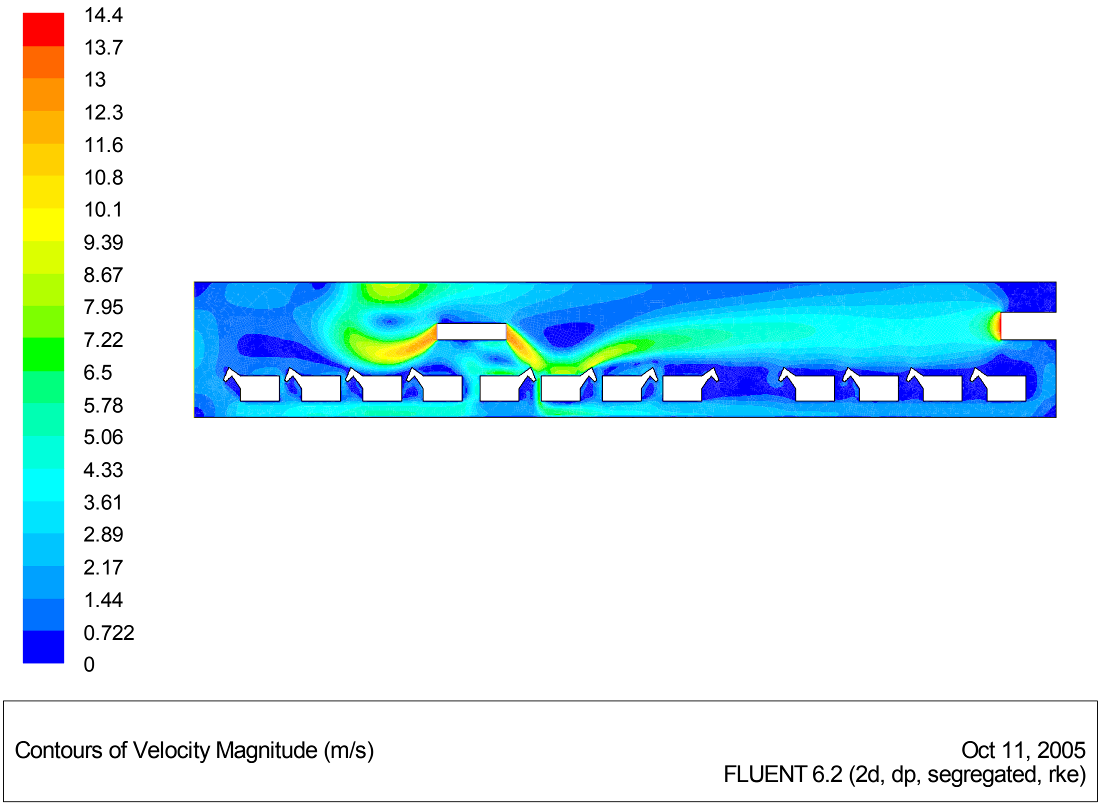


Figure G.11 – Case 5 - Velocity Contours

Velocity Contours within compartment for increased Supply Air Velocity of 12m/s. Stream angle 45° from horizontal as per existing arrangement.

Contours of Total Temperature (c)	Oct 11, 2005
FLUENT 6.2 (2d, dp, segregated, rke)

Figure G.12 – Case 5 - Temperature Contours

Temperature Contours within compartment for increased supply air velocity of 12m/s with existing arrangement. Ambient air temperature at 32°C.

Appendix H

Safety and Hazard Analysis

Safety and Hazard Analysis

The principal safety issues surround the site visit to a Livestock vessel. Due to the nature of the environment on board a ship there a number of significant hazards that need to be addressed in order to maintain safety while on board.

The following hazard analysis identifies and lists the actions required to manage the risks.

Task	Hazards	Risk Level	Action Required
Boarding Vessel	Tripping hazard on gangway	Slight	Use of handrails and suitable safety footwear
Access to and inspection of Stock Housing areas	Slipping hazard on animal waste Injury through contact with animals	Slight Significant	Stay within designated walkways and outside stock pens
Measurement of Ventilation ducting	Falling hazard	Significant	Measurements to be taken only in easily accessible areas
Movement through vessel	Falling hazard on stairs, ladders and access ways	Significant	Use of handrails, stay within designated passageways, Use three points of contact when climbing ladders
Movement through vessel	Striking hazard on low structure, piping	Slight	Use of hard hat and care when on board vessel
Movement through Stock Housing areas	Airborne particles	Slight	Use of dust mask

Table H.1 - Site Visit Hazard Analysis

Beyond the site visit this project also requires a significant number of hours of computer use for both analysis as well as documentation and presentation of results. The associated hazards are analysed in the following Hazard analysis.

Task	Hazards	Risk Level	Action Required
Computer Use	Repetitive Stress Injury	Significant	Correct posture and ergonomic layout of workstation
Computer Use	Eye strain	Slight	Regular breaks, correct positioning of monitor
Computer Use	Back strain	Slight	Correct posture and comfortable seating position. Regular breaks

Table H.2 - Computer Use Hazard Analysis

Appendix I

Project Resources

Project Resources

Table 3 contains a breakdown of estimated resource requirements. At this stage access to the key components such as the FLUENT 6.2 software and computer system have been secured. Upgrade to the computer system has also been carried out.

For the site visit a number of measuring devices are required and will be sourced at the time of the site visit through local supply.

Item Description	Cost
FLUENT 6.2 CFD Software For modeling fluid flow and heat transfer *USQ Supply*	Unspecified
Pentium IV Personal Computer System For analysis, research and documentation of results *Personal Supply*	$1500
Computer Upgrade Increased RAM to run FLUENT analysis *Personal Supply*	$150
Word processing, Spreadsheet & Presentation Software For dissertation & conference presentation *Personal Supply*	$250
Hotwire Anemometer For measuring air flow velocity and temperature *Hired Item - Personal Supply*	$114.52
Infra-Red Thermometer For measuring temperature *Hired Item – Personal Supply*	$119.52

Tape measure For measuring physical parameters *Personal Supply*	$5
Digital Camera For recording images of site visit *Personal Supply*	$500
Personal Protective Equipment Safety Boots, Hard Hat, Safety glasses, Sunscreen *Personal Supply*	$150
Miscellaneous Stationery Supplies Paper, CD-ROM Discs, Printer cartridges *Personal Supply*	$100

Table I.1 - Project Resources

Appendix J

Project Timeline

Project Timeline

Table J.1 presents an approximate timeline for work completed as of the date of Project submission.

Weeks are numbered from the start of Semester 1, 2005.

Submission dates are based on dates presented on the Faculty of Engineering & Surveying project website: http//www.usq.edu.au/faculty/engsurv/project

Project Timeline

Week No.	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35
Task Description	20/05/05	27/05/05	03/06/05	10/06/05	17/06/05	24/06/05	01/07/05	08/07/05	15/07/05	22/07/05	29/07/05	05/08/05	12/08/05	19/08/05	26/08/05	02/09/05	09/09/05	16/09/05	23/09/05	30/09/05	07/10/05	14/10/05	21/10/05	28/10/05
Project Appreciation Submission	16/05/05																							
Background Research																								
Preparation for site visit																								
Site visit																								
Site visit debrief																								
Software setup & familiarisation																								
Modeling of site data																								
Analysis of Model																								
Documentation of results																								
Preparation of Extened Abstract																								
Submission of Extended Abstract																26/08/05								
Preparation of Draft Dissertation																								
Submission of Draft Dissertation																		16/09/05						
Preparation for Conference Presentation																								
Presentation demonstration																			19/09/05					
Conference Presentation																				22/09/05				
Finalise Dissertation																								
Submission of Dissertation																								27/10/05

Legend

Work in progress

Milestone date

Submission date

Table J.1 - Project Timeline